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UGANDA.

(*Three Lectures delivered at the School of Military Engineering by* BREVET-MAJOR J. R. L. MACDONALD, R.E.).

LECTURE I.

UGANDA RAILWAY SURVEY (PRELIMINARY).

IN all such undertakings as the Uganda Railway Survey the attention must be directed to four main points.

First, one has to obtain one's instructions as to the nature and scope of the intended operations, and be sure one fully understands the wishes of the authorities.

This being done, one has to devise the organization best suited to the conditions of the country in which the work is to lie, and best calculated to secure the results aimed at. An estimate of the cost of the proposed operations is generally required in connection with this.

Then follows the work in the field, which divides itself into three more or less well-marked groups: there is first that portion necessary to secure the movement of the expedition without which the country cannot be efficiently examined; there is the actual survey and map-making; and lastly, there is the collection of the necessary information as to the technical details.

Then follows what may be called the office work, which consists in completing in the necessary way the plans, and drawing up the reports and estimates of the railway.

The main points are applicable to all expeditionary work, as indeed are some of the minor ones, while the topographical and technical information required must vary with the objects of the expedition.

The usual course before undertaking any expedition is to get some sort of orders as to the scope and nature of the work, for, until this be known, it is, of course, impossible to insure the best organization to secure the results aimed at by the authorities. In the case of the Preliminary Railway Survey to Uganda the authorities did not seem themselves quite clear on these essential points. They knew they wanted a railway survey from the sea to the Victoria Nyanza, and an estimate of the cost of such a railway, but they were not altogether sure whether to work from Mombasa or *viâ* the Tana River, and were still more undecided as to the nature of the survey which I had to undertake. The result was that, instead of my getting exact orders as to my work, I found that I was called on to give an opinion as to what should be done. Two points were, however, laid down; the survey must be a rapid one, for an inexpensive line, and must be completed within a year, and—perhaps a still more important point—it must not cost more than a specified amount.

Now a railway survey is a fairly comprehensive term. First comes the railway reconnaissance pure and simple. A qualified engineer traverses the country and takes barometric or other levels, and, from the nature of the country and general levels, decides on the route the line should follow. He also roughly estimates the cost of the line by alternate routes by comparison with lines through similar districts which have actually been built in the country. A skilful engineer will make a wonderfully accurate guess at the cost of a line in this way.

Then follow various trial lines, in which the distances are measured and not estimated, and flying levels are taken. These trial lines still further restrict the choice of the ultimate alignment by eliminating alternatives that may be unsuitable by reason of their difficulty, comparative costliness, or of other considerations. After this follows the detailed survey, in which levels are taken at every chain,* and cross sections are made at similar distances to enable the engineer to decide if he can improve the line by shifting the alignment in places a little one way or the other, and to enable him to estimate the amount of the work in excavation, etc. This survey may be sufficient to base the estimates on, or it may be necessary to make another. Then, and not till then, can the line be staked out ready for construction. This may sound rather a complicated and laborious process, but it is an axiom that money is well spent on a careful survey.

Now the time and money limit made it quite impossible that I should attempt a survey in all its details, but at the same time a

* In India the chain of 100 feet is always used.

bare reconnaissance would have been insufficient basis for a reliable estimate, as there were no existing lines in East Africa, and the conditions of country, climate, labour, etc., were quite different from those in India or the Cape. I decided, therefore, to attempt something more elaborate than a railway reconnaissance and something less than a survey.

This having been settled, the next point was to decide on the strength and organization of the survey party, and to frame an estimate of its cost. To enable me to arrive at this, a large number of books and reports were placed at my disposal, but as East Africa was a little-known region, this literature, though interesting, was not of much practical use. After several days the Directors of the Imperial British East Africa Company sent for one of their employees, who had lately returned from Uganda, and a couple of hours' conversation with this gentleman proved of more value than all the books together. It is certainly an immense advantage to have a talk with a man who has recently traversed the country in which your labours are to lie, even if, as in this case, he should not be an engineer.

Having got all I could out of Mr. Gedge, the Company's officer, I set to work to frame an estimate of the cost of the survey expedition. This involved going into the number, pay, passages, allowances, etc., of all the staff, both officers and subordinates, and followers; the instruments and drawing materials, stationery, etc., had to be allowed for; the tents, camp equipage and tools had to be provided; arms and ammunition had to be purchased; special arrangements for feeding the men imported from India had to be considered; the transport necessary and the scale of transport for each member of the expedition had to be fixed; allowance had to be made for boats and other special articles; and last, but not least, an estimate of the trade goods, that is to say, cotton cloth, beads, brass wire, iron wire, and the other things that take the place of money in the interior of Africa, sufficient to feed the expedition for our long absence in the interior, had to be formed. The cost of working out the results of the survey had also to be included in this estimate.

The authorities pressed for an early submission of the complete estimate, and I got it ready in a week. Needless to remark, it cost me a good deal of labour, but I am happy to say that the actual cost of the completed survey was found to be a trifle under the estimate I submitted at this time.

My proposals and estimates were accepted, and I was permitted to secure my staff. In this I was fortunate, and Captain J. W. Pringle and Lieuts. Twining and Austin, of the Royal Engineers, all of whom I knew personally, and with whose ability and power of work I was well acquainted, were enrolled as engineering staff. I may as well at this point acknowledge how much I was indebted to these officers for the zeal and energy with which they entered into the work and supported me from beginning to end. No one could have had a better staff for the work in hand than I was fortunate in securing. In addition to them, I was to get two of the Company's employees as transport officers, and the subordinate staff was to consist of two native surveyors, two draftsmen, and forty Indian Khalassies, with two hospital assistants.

The expedition was to be organized in two self-contained divisions, each consisting of two engineers and one transport officer, with a due complement of subordinates and transport. These divisions were to work independently between points, to be arranged as circumstances might require, where they would meet to compare results and check their work.

We may now refer to the map while I show approximately what was known of the country before we started. By this time it had been settled by the authorities that Mombasa was to be the terminus at the coast; this decision was due to the fact that Mombasa possesses two excellent harbours.

At the further end we were at liberty to make for any point on the Victoria Nyanza which lay within British territory, that is to say, north of the 1° south latitude. But between these points stretched a great valley known as the meridional rift; this could not be avoided, as it stretched nearly due north and south from German territory to Lake Rudolf. From all accounts, this rift, bordered by almost precipitous escarpments, would prove a very formidable obstacle, and might necessitate a more or less circuitous alignment. Sir Guilford Molesworth, a very eminent railway engineer, from the somewhat scanty information furnished by a rough exploration map, had hazarded the forecast that a possible alignment would probably have to ascend the great Mau Escarpment, where the subsidiary spurs of Kamasia leaves the parent range, and, as it subsequently turned out, his forecast was correct. But it devolved on us to examine a considerable length of the escarpment to see where the most feasible ascent might offer. It was evident this spot would prove an obligatory point on the railway, and might thus cause the alignment to depart widely from the most direct line between Mombasa and the Great Lake.

I may now describe generally what was known from the experience of previous travellers. From Mombasa there was a sharp rise in somewhat difficult country for 15 miles, until the first step of the interior plateau was surmounted. Then the country was more easy, but without food till Teita was reached, and between the rockpools of Taru and the mountains of Teita there was known to exist a waterless tract of two long days' march. After Teita there came seven days' march without food, until the cultivation of Kikumbuliu was reached. This country, like all from the coast, was covered with scrub jungle, but was not without water.

An alternative route to this point ran north from Mombasa through the hilly country inhabited by the Giriama tribe, until the River Sabaki was struck at Makangeni. Thence the Sabaki and Athi Rivers were followed to Kikumbuliu, through forest and jungle, in which there were no inhabitants, and where it was necessary to carry food for about 14 days.

From Kikumbuliu, four days' march brought the traveller to the fertile and mountainous region of Ulu, inhabited by the enterprising but peaceful tribe called Wakamba. Right from Teita to Ulu stretched on the north a line of hills called the Kyulu Mountains, and beyond them lay great grass plains inhabited by the warlike and turbulent Masai. From Machako's, the Company's post in Ulu, four long marches across open grass steppes, the grazing grounds of the Masai, led to the forest and mountains inhabited by the treacherous Wakikuyu, who had only recently captured the Company's fort at Dagoretti.

In Ulu and Kikuyu there was abundance of food, but beyond the latter stretched a great foodless tract, either uninhabited or occupied by wandering Masai. Through this tract caravans carried food sufficient to last them for from 15 to 24 days, according to the route they selected—a formidable undertaking. The usual trade route descended into the meridianal rift at Kikuyu, and travelled north along this until Kamasia was reached. Here a little food could sometimes be obtained in favourable seasons, and from this the caravan struck due west to the Victoria Lake, and the rich country of Kavirondo, crossing on its way the three ranges of Kamasia, Elgeyo, and Elburgoloti. This was the route followed by Joseph Thompson, Bishop Hannington, Captain Lugard, and others, but, to judge from their accounts, was hardly suitable for a railway.

Captain Eric Smith had tried a more southerly line, and got through to the lake, but a portion of his caravan had been surprised, and lost more than 30 per cent. of its numbers, in Sotik. Jackson and Gedge had struck west to the north of Smith's route, and had nearly lost their caravan in the impenetrable forests of Mau; they were saved from starvation by a chance meeting with some Wanderobbo hunters, whose services they impressed as guides, and whose stores of dry meat were requisitioned. James Martin had explored a new route still farther north, and had got on to the Guash Ngishu Plain, and so to North Kavirondo.

These four routes had been attempted. The most northern we knew pretty well beforehand was impracticable for a railway, and the three others all encountered more or less of almost impenetrable foiest and rugged mountains, and necessitated the transport of 15 to 24 days' rations for an ordinary caravan. For a more slowly moving body like the survey expedition, food would have to be carried for 24 to 36 days, and this alone meant a very great deal of transport. We knew that all along west of the mountains of Mau stretched a belt of dense forest of varying breadth, which separated the grass plains of the Masai from the agricultural districts that bordered the great lake, and, unfortunately, in this region of mountain and forest, where there was no food but what we could carry, lay the most difficult part of the work.

From this knowledge of the country I made out the following general scheme. The expedition was to be collected at Mombasa, and the transport was to consist of about 250 porters and 120 donkeys. A food depôt was to be made at Tsavo, and another at Makangeni, before our arrival; food was also to be purchased and stored at Kibwezi in Kikumbuliu, and at Machako's in Ulu, and trade goods for our use were also to be sent to both places. Beyond Machako's, 300 miles from the coast, no preliminary arrangements were possible.

One other point I should touch on. The authorities more than feared that the survey would be opposed by certain of the tribes, and hence we went prepared to fight. To this end our Indian Khalassies, recruited from Pathans and Punjabi Mahommedans, were to be armed and drilled, and a large proportion of our transport followers, Swahilis, were also armed with Snider rifles or carbines. In all we carried 20,000 rounds of ammunition, of which 1,000 were loaded with buckshot for night work. The authorities urged me to take a Maxim gun, but this I decided to do without.

We could not get a Maxim to take Snider ammunition, and to carry the necessary amount of special ammunition, without which the Maxim would be of little use, would have added too much to our transport. Moreover, the Maxim, though very valuable in some cases, is hardly a general service weapon, and is practically useless in bush and jungle.

By leaving out the Maxim I was able to carry two Berthon boats, one for each division. Each boat was in two sections, and when fitted up was about 12 feet long, and would carry, as we practically proved, six porters with their loads, exclusive of the boatmen. These boats proved most useful in the exceptionally rainy season we encountered, and, used as flying bridges on cables stretched across the rivers, were very serviceable. They stood the climate better than I expected, and we left them behind in Uganda. Two years afterwards one was still in use; the other was captured and destroyed by the enemy during the Mahommedan rebellion in 1893, otherwise, no doubt, it would have enjoyed an equally long life.

I will leave the description of our instruments until I describe our method of work, as I am now endeavouring to give some idea of our general organization. The distance to the lake was supposed to be about 600 miles, and I estimated that, working in two divisions, we could, in seven to nine months, survey, going and coming, about four times this distance, or about 2,400 miles, working at the rate of 40 miles a week. This forecast was fairly accurate, as the survey expedition was in the field nearly nine months, and actually surveyed 2,724 miles. Up to Machako's, 300 miles from Mombasa, we had no reason to anticipate any very great difficulties as regards physical obstacles to a railway, except in passing the Ulu Mountains, and our food problem was simplified by our having depôts of stores prepared beforehand. This not only facilitated our work over the first half of the distance, and allowed us to pass more quickly over the unhealthy part of the journey, but it also enabled us to devote more time to the second and more difficult half of the route.

I have dwelt at some length on this preliminary portion of our work of organization, as it forms a most important portion of any such expedition. Time and trouble devoted to such preparation is repaid again and again when the expedition is once launched into the interior, and its working organization is put to the critical test.

All this preparation did not work quite smoothly—it never does. There were certain technical difficulties between the Directors of the

Imperial British East Africa Company and the Government, which I need not dwell on beyond mentioning that they prevented our spending any money, and thus hampered our arrangements. Finally, we got less than a week's notice, and were told one Monday morning that all the instruments and stores must be bought and shipped by the following Saturday. Fortunately Captain Pringle and I had made out complete lists of everything necessary, and so by working from morning to night we managed to get what we required. I had warned the Directors that the best instruments could not be got in a day, and that several of the best makers required five or six weeks' notice; but my warning was of no avail, and at the last moment we had to buy what we could in the market. There was just time to have the instruments tested at Kew, and, take it all round, we found they were more satisfactory than might have been expected.

While Pringle and I were so engaged at home, Twining and Austin were busy in India collecting the subordinate staff, and the Company's agents in East Africa were arranging for the necessary transport and stocking the depôts. Finally, on the 24th November, 1891, the survey expedition landed at Mombasa.

There was still much to be done before we could take the field. It turned out that the transport was not ready, some 50 out of the 120 donkeys that had been purchased were already dead, many more seemed likely to follow suit in a few days, and one of our transport officers was still some hundred miles in the interior, and quite out of reach of orders. Some of the depôts had not been stocked with provisions and trade goods, but we were assured that they would be ready before we reached them. Then all the stores, etc., that we had hurriedly bought in England had to be re-packed into loads of 65lbs. to be suitable for the porter transport, and various other items had to be provided locally. All this gave us plenty to do. The engineers had also to be practised in astronomical work, so our days were occupied in arranging loads, enlisting porters, and similar work, while the evenings saw us diligently star-gazing.

To add to our discomforts, there was a great deal of rain, and the Company's employees assured us it was an exceptionally rainy season. This turned out to be the case inland as well as at the coast, and had the effect, amongst others, of raising the Victoria Lake some three feet above its normal level. This rain, though it considerably increased our discomforts, had the double advantage that it decreased our difficulties as regards water, and enabled us to get a better idea than we otherwise should have done of the bridging necessary for the rivers and streams.

Our caravan, when complete, mustered 389 men and 60 donkeys, but 10 more of the latter died before we started. Pringle and I had made two short expeditions into the coast hills during this period of preparation, and on the 18th December the second division, under Pringle and Austin, left Mombasa to examine the ordinary trade route to Tsavo. Six days later the other division, under myself and Twining, started northward to investigate the Sabaki route and meet the other party at the food depôt at Tsavo. Pringle was given 30 of the best donkeys to carry water across the Taru Desert, while I took the remaining 20, many of which were, however, in a very weak state. With Pringle went Mr. Jackson as transport officer; the transport officer for my division was still somewhere in the interior, and so I lost his services at the start, when they would have been most valuable.

I need not describe the exasperating details of starting a caravan in East Africa. The Swahili porter, when once well away from the temptations of the grog shops at the coast, is a very fine fellow, but for the first few marches he is an unmitigated nuisance. Some men turn up late, others do not turn up at all, and have to be searched for, some grumble at their loads, while others seize a light one and disappear into the jungle. The donkeys were even worse than the men, and altogether one must possess a most unusual amount of patience if one is not to lose one's temper not once but many times during the first week. It is impossible to insist on very strict discipline at once, as the men would desert, in fact, every caravan calculates on a certain percentage of desertions. I may mention that in one night 24 of our men went off in a body; I am glad to be able to say that most were ultimately re-captured and had to fulfil their engagement.

Pringle reached Tsavo by the 11th January, having had a fairly uneventful journey of about 140 miles. The waterless tract had been traversed in three marches; for one day water was obtained from a shallow pool of rainwater, and the supply carried on the donkeys tided the division on to the rock pool of Maungu. At Ndi he had a good deal too much water, for a mountain stream, flooded by the rains, burst its banks at night and nearly swept away the survey camp. Officers and men had to turn out at short notice and dig trenches and throw up banks to divert the water, which threatened to carry all before it.

On the 18th January the first survey division reached Tsavo *viâ* the Sabaki River, after a march of 150 miles. We had experienced more variety than our comrades of the second division. The second days' march led through swamps and boggy ground, and had proved too much for our donkeys, who by 11 p.m. were all comfortably installed for the night in different bog-holes, from which their exhausted drivers could not extract them. Next day we had to halt to recover these useless animals, and then pushed on again.

The heavy rain had magnified all the little streams into obstacles, and the jungle and grass were very wet and unpleasant. To improve matters the caravan fell amongst bees and scattered; it took us some hours to recover the loads from the infuriated insects, and one man nearly lost his life. Two donkeys were killed by the bees, and one of our Europeans, a surveyor, was rendered quite ill by the stings. The man who had been so badly stung, an Indian Khalassie, had to be carried into camp in a hammock, and the whole day's march only came to about $4\frac{1}{2}$ miles.

Our 20 donkeys had in these four days rapidly dwindled away, and were now represented by 12 sickly animals which could hardly support themselves, let alone their loads, so Sergeant Thomas and the sick Indian, with some local porters, were sent back to Mombasa with the donkeys. Sergeant Thomas had orders to engage porters, to replace the donkeys, and push on to Tsavo by the main trade route. He, however, stuck in the coast swamps for a night, and on reaching Mombasa got seriously ill and spent a month in hospital. He ultimately joined us 300 miles inland with some fresh men.

Having got rid of the donkeys, we pushed on more rapidly through hilly country inhabited by scattered groups of the Wagiriana. But the rain had made the country very unhealthy, and at one place I had Twining, 19 out of 21 Indians, and perhaps 30 per cent. of my porters, down with malarial fever. Ultimately we reached the Sabaki River at Makangeni, only to find that one of the Company's contract caravans, which ought by this time to have reached Kibwezi to stock that depôt with trade goods and food against our arrival, was stranded here, and was unable to proceed owing to numerous desertions.

Relieving this caravan of a number of loads of food, which we issued as rations to our men, we were able to induce it to accompany us up the river. The banks of the Sabaki, which is a fine but unnavigable river, are uninhabited, and clothed in more or less dense jungle. The Company had cut a road through the bush for four marches, and we saw the gentleman who had been engaged on this pestilential job returning to the coast a wreck with fever. Soon we found no road at all, and for seven days had to cut our way through the bush to Tsavo. The contract caravan did not accompany us, as on reaching the end of the road they threw down their loads and bolted for the coast. We could not possibly carry on some 150 extra loads, so there they remained until the Company sent for them later.

Thanks to the heavy rain, the Sabaki route had proved a most unpleasant one, and frequently we had to wade through swamps or accumulations of water waist deep. Game there was in abundance in the jungle, and hippopotami sported in the river, but the undergrowth was so dense that we got but little sport.

At Tsavo the two divisions compared notes and checked their work. Reports, plans, and a rough estimate were made out for the Directors at home, and meanwhile Twining and Austin, with a strong party, carrying 18 days' rations, were sent off to continue the traverse up the Athi River, as the Sabaki was now called after its junction with the Tsavo, and a fresh meeting place was arranged at the foot of Nzoi Peak, about 100 miles ahead.

Meanwhile, after sending off our mails, the rest of us followed the trade route towards Nzoi, but on the second day Mr. Jackson fell seriously ill. Our hospital assistant could do nothing, and we had to carry our comrade to Kibwezi, where there was a Scottish Mission station and a doctor. The Kibwezi Mission had only been started about nine months, but already looked a pleasant settlement, where we would willingly have lingered a few days, but this we could not do. Loading up with food, we pressed on, leaving, to our great regret, Mr. Jackson in the doctor's hands. He never re-joined us, but was invalided home.

A little beyond Kibwezi there is a gap between the Kyulu and Ulu Mountains, through which flow two rivers. Here at last we caught glimpses of the end of the great belt of scrub jungle through which our work had lain for so long. But though observations pointed to a practicable railway route through this gap, we had to push on to the great granite peak of Nzoi, which loomed before us, and marked our meeting place with Twining's party.

Nzoi was reached on the 10th February, and on the last march we lost our first man. He had been sick, and was riding on a donkey when the caravan was attacked by bees. The donkey bolted, and threw his rider under the tree on which the beehives—

hollow logs—were suspended, and the venomous insects settled on him in thousands. As soon as we discovered he was missing, a few volunteers rushed back, and, after many stings, got him away, but the poor fellow died the same afternoon.

Next day Twining's party joined us. They had found the Athi much like the Sabaki, and that progress was slow, owing to the dense vegetation through which a path had to be cut. After 16 days, as their provisions were running short, they left the river and struck across country by an old native path towards Nzoi, as they hoped, but the path led them to the wrong side of the mountain, and they had to march round it to reach our camp. Their provisions had just run out when they reached an inhabited district of Ulu and found themselves in the midst of plenty.

The re-united caravan halted a few days at Nzoi, amongst a number of flourishing Wakamba villages, not only to get the mapping, etc., up to date, but also to rest the men. During this halt Pringle and I ascended Nzoi peak, the summit of which rises to a height of about 6,000 feet above the sea. The last 1,500 feet appeared a sheer precipice, but native guides showed us a narrow ledge that ran up the face of the cliff at an angle of about 45°. This ledge was sometimes 30 feet wide; at other points it dwindled down to a breadth of only 3 or 4, and at one place it ceased, and we had to climb along the face of the cliff by little footholds. At this unpleasant spot the inevitable bees, which seemed to infest the country, swarmed out of some small caves and attacked us. Those of us who happened to be above the difficult portion fled up the ledge; those of our men who were behind made a rapid and noisy retreat downwards. Fortunately for us, the bees followed the more noisy party, and no damage was done, as the men easily escaped down the ledge, although at some risk to their necks.

From the summit of the mountain, which was breast deep in bracken, we got a magnificent view. My opinion that the most feasible route for a railway ran along the Salt River gap between the Kyulu and Ulu mountains seemed confirmed, but we could not do much more than admire the scenery, as the man with our theodolite was amongst those who had been driven downhill by the bees. Those same bees kept us on the side of the cliff until after sunset, and it was only after they had gone to bed that we could venture to crawl downwards in the fast failing light.

We had now reached the first of our natural obstacles, the Ulu Mountains. The results of our work up to date had shown two practicable routes as far as the Salt River. From Mombasa the line would have to run *viâ* Taru to Tsavo, and from this point there were two alternatives, one more or less following the trade route through Kibwezi, and the other following the Athi River. Beyond the Salt River neither of the routes was wholly satisfactory. It now remained to find a good alignment through or round the Ulu Mountains. The second division was sent back along Twining's route to a river he had found, a branch of which appeared to flow through a comparatively easy valley from the north. The first division examined the ordinary trade route, and both were to meet at the Company's station at Machako's.

On the 20th and 23rd February the first and second divisions arrived at Machako's, both to report that the passes examined were unsuitable for a cheap railway, though practicable for a very costly one. The problem of a passage through the Ulu Mountains was still unsolved.

We were, moreover, now face to face with the inhospitable country that separated us from the fertile districts on the lake shores, for a plague of locusts had destroyed the crops in Kikuyu, and all our portable food must be carried from Machako's. The expedition now mustered 450 of all ranks, and I estimated we must start from Machako's with about 45 days' rations, which meant 610 loads of food. Our other loads amounted to over 400, so we had to carry well over 1,000 loads of all kinds. To do this we had available 210 porters, after deducting such detachments as were necessary to allow of work being continued and food brought in, etc. Our donkeys had dwindled to 20, but Foaker had got 30 more at Machako's, so that we could handle about 300 loads at one time.

In the circumstances, I decided to form a food depôt at Kikuyu, which would require three trips from Machako's to stock, and then by two more trips form a second advanced depôt at Lake Naivasha, about 50 miles farther on. While this was being done a survey party would continue work on the Ulu Mountains, and endeavour to find a decent route for the railway.

Two days after the two divisions had assembled at Machako's the first food caravan for the Kikuyu depôt left, under charge of Mr. Foaker, with about 300 loads of food. Twining accompanied this party to look after the Kikuyu depôt and do some survey work there. One officer remained at Machako's to see to the collection and packing of food, while two others started to examine the passes north-east of Machako's. This party was absent 10 days, but diverged rather too much to the north, and failed to do much as regards the railway, though they added a little to our geographical knowledge of the Ulu group of mountains.

Another party was led southward by myself, and was more successful. On the fifth day we got clear of the main mass of hills, and on the sixth, after careful work with the theodolite, decided that a fairly easy ascent from one of the tributaries of the Salt River on to the Kapote highlands was possible. Food running short, we had to retrace our steps to Machako's. We had now found that the route *viâ* Kibwezi could be prolonged from the Salt River on to the Masai steppes of Kapote, and with this I was satisfied for the time, and decided to leave the further investigation of the Athi River route till the return journey.

The food depôt at Kikuyu had now been formed, so the whole expedition marched from Machako's and reached Fort Smith, in Kikuyu, by the 24th March. The line across the Masai plains was easy, and the country was now open, which greatly facilitated our work. The plains were swarming with game of all kinds, and as rhinoceros, hippopotamus, and antelope fell to our rifles, our followers were in high spirits with plenty of meat.

At Fort Smith Twining had not been idle, and had surveyed for nearly 20 miles ahead to the edge of the Kikuyu encampment. Fort Smith—named after its founder, Captain Eric Smith, of the Life Guards—was a strong and well built work, containing several brick houses and numerous stores, etc. After the Company's post at Dagoretti, founded by Captain Lugard, had been captured by the Wakikuyu, Captain Smith had been sent by the Directors to re-establish the station. He had, however, found a more favourable site, and built a strong fort without opposition. This fort was afterwards the scene of a good deal of fighting, but that is another story.

After a few days' halt I pushed on with the bulk of the expedition to establish our advanced depôt at Lake Naivasha, leaving Pringle at Fort Smith to complete Twining's work. At the Kikuyu escarpment we had two days' hard work ; Twining had already found a suitable place for a descent into the meridional rift. This descent was, however, a formidable affair, meaning a drop from an altitude of 7,200 feet to about 5,800 in a few miles, and I had to satisfy myself that it was practicable for a railway. This I did, out as the temperature dropped suddenly towards evening at these altitudes, I caught a violent internal chill which incapacitated me for nearly a week. The hard and incessant work had also told on the other engineers, and all were somewhat out of sorts and suffered from fever. We now pushed on along the meridional rift to Lake Naivasha, which we reached late on the afternoon of the 1st April. Next day a strong boma or zareba was built near the lake shore, and the food got under cover.

On our journey from Kikuyu we had met the redoubtable Masai for the first time, and their advent caused no little consternation among our Swahili followers. A party of 17 *elmoran* or warriors came and demanded *hongo*, which, being translated, means transit dues. This was refused as a matter of principle, and after a short parley the Masai walked off.

These Masai are an interesting pastoral people, whose main source of income consists in the cattle of their neighbours. Twice a year raiding parties are sent out, and these war parties travel immense distances in search of cattle. Their organization is peculiar. Every able-bodied bachelor is *ipso facto* a soldier, and the soldiery must camp separate from the married people. The latter may, and do, surround their kraals, or rather camps, with a fence, but the Masai *elmoran* or warriors must have no such passive defences, but must trust to the alertness of their picquets to guard against surprise, and to their spears and shields to ward off attack. The warrior must not eat vegetable food, but is supposed to live on milk and meat. I say supposed, because the famine consequent on the cattle plague which some years ago devastated East Africa has caused some relaxation of this rule. There is a still further restriction as to diet, for a warrior cannot dine on milk and meat at the same time, but on one or other. When he begins to find this strict *regimen* and the trying raids are telling on his strength he may, if he has shown his prowess by killing an enemy, marry, and move to the married kraal and become a more respectable member of Masai society.

The Masai are a very brave and hardy race, and are not treacherous. They have a strict discipline in their armies, and have a system of drill and organized attack. But I have not space to dwell longer on a description of this fine material for our future recruiting grounds, but must hasten on. I may say that, with one exception, the Masai were very friendly with us, and though they have more recently massacred a European and 1,000 Swahilis out of a caravan of 1,200, I think this was done by the Masai of Lykipia, and not by our friends of the meridional rift. The Masai of Lykipia are a distinct branch of the tribe, who live in the highlands north-west of Mount Kenia, and have not had the same acquaintance with Europeans, and were, moreover, prejudiced against them by their experiences at the hands of the notorious Dr. Karl Peters.

While Austin, Sergeant Thomas and I, with 40 men, remained at Naivasha to guard the food depôt, the rest of the caravan returned to Fort Smith to bring on the second instalment of food and other loads. Meanwhile Austin and I set out to survey round Lake Naivasha. I was re-called to the depôt by the arrival of a caravan from Uganda under James Martin. His news was most serious. A civil war had arisen in Uganda, and Lugard and the Company's officers were supposed to be beleaguered in Fort Kampala. Two officers were reported dead, and Martin had been unable to force his way to Kampala or open communication with Lugard. This was grave news, and I at once sent word to Pringle to bring on all our reserve ammunition from Fort Smith, instead of the presents which had been destined for King Mwanga.

On the 16th April we had all re-assembled at Naivasha; two days later the two divisions again separated with orders to meet at Mumia's, in North Kavirondo, in a month's time if possible. Pringle was to explore the route west to Ugowe Bay through Sotik, while my division examined the Mau Escarpment, and endeavoured to find a practicable route on to the Guash Ngishu, and hence down one of the tributaries of the Nzoia River.

Pringle reached Mumia's on the 18th May, having met with no opposition, though most of the Company's employees prophesied fighting in Sotik. Twice, it is true, the inhabitants threatened to attack the camp at night, but the discharge of a few rockets and the use of the small portable search light, with which each division was provided, made them think better of it. Once, while Pringle was searching for a good site for a bridge across a swollen river, he was nearly rushed by a band of spearmen, but Austin turned up in time with 50 rifles, and the enemy retired without fighting. The Sotik route was not a success, as it not only crossed Mau at an altitude of over 10,000 feet, but had to negociate a mass of minor hills and ravines that would have made the railway a very costly one, and with heavy gradients and sharp curves.

The first division reached Mumia's on the 16th April, having met with better luck. At one place the Masai mustered on the far side of a ravine, and a conflict seemed imminent, but after a short conversation with their chief I was able to convince him that it would be better to remain friendly. Travelling northward past the salt lakes Elmenteita and Nakuro, over beautiful grassy plains, in many places covered with clover, we began the gradual ascent of Mau.

Where Kamasia leaves the parent range we found a good alignment, and, after negociating the famous Eldoma Ravine and spending two days in a gloomy forest of perpetual twilight, we emerged on to the grassy plains of the Guash Ngishu at an altitude of over 8,000 feet. For two days the country, though it looked easy, proved rather difficult for the line, as a number of steep little valleys, all discharging into the main river Ndo, which flows between Kamasia and Elgeyo, made it necessary to curve about a good deal. Once Elgeyo was surmounted, at an altitude of 8,700 feet, it became plain sailing, as we struck one of the tributaries of the Nzoia River and followed it down through easy ground. The valley of the Nzoia also proved fairly easy, though in one place this large river plunges in a succession of falls into a ravine 150 feet deep.

The almost incessant rain—it rained for 23 out of 24 days—had proved very trying to both divisions, more especially as it was very cold at the high altitudes attained. The rivers were also exceptionally flooded, and caused a good deal of trouble, more especially on the Sotik route. The constant rainy weather had also rendered the astronomical work unusually severe, as we had frequently to get up at night to take advantage of some temporary break in the clouds reported by the sentries. Twining had also been seriously ill, and for fourteen days had been carried in a hammock as we could not halt for long in the foodless tract.

Still, when we re-assembled at Mumia's we were in good spirits. Twining had almost completely recovered, and a practicable railway route had been discovered. The news from Uganda was also re assuring, as we learned that Lugard had overcome all opposition, and that the road was once more clear.

Leaving Austin in Kavirondo to buy food and make preparations for the return journey, the rest of us pushed down the Nzoia River and found a good line, to within ten miles of the Victoria Nyanza. Twining and Sergeant Thomas were now detached with 100 men to complete the survey by finding a suitable terminus and harbour, while Pringle, Foaker, and I went on to Uganda with mails and ammunition for Lugard.

By the end of the first week in June Twining had completed his work, and he then relieved Austin at Mumia's. The latter did some useful work towards Mount Elgon while waiting for the return of the Uganda party. This party, marching rapidly through the banana groves of Usoga and the swamps of Uganda, reached Kampala on the 9th June. Seven days later it commenced the return journey, and reached Mumia's on the 4th July. All this time it had rained for two days out of three, and the discomfort had been great. Lugard, with a caravan of 160, men, women, and children, had attached himself to us for escort through Masailand, and this necessitated the collection of more food.

At Mumia's we found our men had been attacked by small-pox, which Martin's caravan had brought into the district. The exceptionally rainy season had also killed off a lot of our donkeys, and one way or another our carrying power was reduced by 150 loads. However, our men, now that their faces were turned homeward, did not mind increased loads, and by leaving our Berthon boats and other impedimenta behind, we were able to carry enough food for our men for the return journey, as also 29 loads of food for Lugard's caravan, which could not carry enough for itself.

On the 7th July we said farewell to Mumia's, and marched homeward for five days as a combined caravan. Then we were stopped by flooded rivers and lost about two days in bridging them. This was a difficult operation, as we had to extemporize rope from hides and the bark of the wild fig-tree. The timber was mostly short, and over the first torrent, which was nearly 50 feet wide, we had to make a cantilever bridge on the Kashmir type. The second river was easier to bridge, as we got a few long trees to span the stream; these, laid side by side, and strengthened by piles, proved strong enough to support a roadway.

Here we again divided into two parties. Pringle and Austin travelled *viâ* Baringo to Kikuyu, and arrived there on the 9th August without incident. The incessant rain had rendered the rivers and streams very difficult, and they had to build two more bridges of nearly 100 feet in length.

The main body, hampered with sick donkeys and a tail of small-pox patients, many of whom had to be carried, travelled along the route of the first division. I branched off for five days, accompanied by Foaker, to examine the Guash Ngishu plains. We had a poor time. It rained incessantly. We had to bridge one stream, on whose banks grew a few trees, and then passed into a grassy, treeless country. A second flooded river we crossed on a light trestle bridge made of tent poles and porters' staves, a very flimsy structure, which, however, allowed one man to pass at a time. For two days we had not a stick of firewood, and had to do our best with such cold rations as we had. Uncooked porridge is not palatable, and we were all glad to get back into forest country once more.

Picking up the main body, we marched slowly to the great ravine in almost daily rain. We could not shake off the small-pox, and the donkeys got more and more feeble. At the ravine we got rid of the donkey loads of flour by issuing 10 days' rations all round, and pushed forward by long marches towards Kikuyu. The Morendat River was in flood, and as no suitable timber for bridging was to be had, we made a détour round Lake Naivasha, and reached Kikuyu on the 7th August.

So far all had gone well. The only point I regretted was that we had been unable to examine a route through the Nandi country. Judging from the difference of altitude of the Guash Ngishu plateau and the lake districts, this did not promise a line with an easy gradient, but I should have liked to examine it. Hampered, however, with Lugard's unarmed caravan and our train of sick, I could not attempt to fight my way through Nandi, for it would have meant fighting.

At Kikuyu Lugard and his followers left us and pushed ahead. The survey caravan was delayed a little, as the Company's agent had got into trouble with the natives. His headman and a small detached party had been massacred, and he appealed to us for help. This led to a small punitive expedition, lasting a few days, and resulting in one fight, when with about 150 men we defeated about 800 of the enemy, and compelled them to give in. An attempt on the part of a native chief to assassinate the Company's agent further delayed us, and it was not until the 17th August that we left Fort Smith.

On the return journey I intended to examine three sections of the route. Austin and I were to link in the portion of the Athi route which had been left undone, and so branched off with 18 days' rations. We started with rations for 19 days, but one donkey was killed by bees, and we could not recover its loads. Pringle I detailed to examine the Salt River, and Twining to survey the Kibcko River. All three parties were to assemble at Kibwezi, where I had asked the Superintendent of the Mission to lay in a supply of food. We had also arranged for the replenishment of the food depôt at Tsavo.

News, however, reached us that Tsavo was empty, and that the crops had failed at Kibwezi, and there was famine in the land. This necessitated a change in our operations. Foaker pushed on to Ndi to buy food, Twining set to work to carry food from Machako's to Kibwezi, while Pringle, with a small party, examined the Salt River. Austin and I had already started to carry out the Athi survey. These plans, as modified, were successfully carried out, and all three parties met at Kibwezi on the 7th September. Pringle had found an ascent on to the Kapote plains which was easier than the one I had previously investigated from Machako's, while Austin and I, after laboriously cutting our way through the Athi bush, had found that that route also was quite practicable for a railway, but somewhat longer and more costly than the one examined by Pringle.

I now intended to explore the valleys of the Mtondai and Tsavo Rivers by flying columns, but at Kibwezi I got orders to return to Uganda. Neither of these minor expeditions promised much, so Pringle, to whom I handed over charge on the 10th September, led the expedition straight to Mombasa, which was reached on the 23rd of the same month.

Though when we left Mombasa the previous December we were in the midst of an exceptionally rainy season, we found on our return that the summer rains had failed in the coast region, and that there was a consequent drought and failure of crops. We had thus the double advantage in the coast region, which we may assume in this connection to mean about 300 miles of the route, of seeing the flood discharge of the rivers in exceptional rain on our upward journey, and of gaining some idea of what difficulties the line might experience from drought on our return journey. During our travels in the inland section of the route, which embraces the whole of the remaining 350 miles, we were dogged by a heavy and continuous rainy season of exceptional severity, as is borne out by the rise of three feet in the level of the Victoria Nyanza, and by the subsequent experience of myself and other travellers.

Before I handed over charge to Captain Pringle at Kibwezi I had already drafted my report on the technical portions of the work, and put into shape the basis of the estimates, and, as the maps were also well up to date, I had no misgivings as to the completion and editing of the necessary blue-book. Nor was I disappointed, for this arduous work was admirably carried out by Captain Pringle, assisted by Lieutenants Twining and Austin.

Having thus briefly described the expedition, I will endeavour to give you some little idea of the actual survey itself, as carried out by each division. This divided itself into two well-marked groups:

the topographical work necessary for the preparation of the maps, and the technical matter required for the report and estimates.

Dealing first with the topographical portion, I may preface my remarks by pointing out that more was expected of us than was strictly necessary from a railway point of view. While bearing in mind the main objects of our expedition and subordinating other considerations to them, we had also to map in as much detail as we could, whether it bore on the railway or not.

Our survey was based on a traverse run with prismatic compass, the distances being found by three pedometers per division. This traverse was plotted on a scale of one inch to one geographical mile, which, as we were near the equator, meant one minute of latitude or longitude. On arrival in camp this was put on to a plane table sheet on half the scale, and such detail as was possible was then worked in by plane table survey from neighbouring high ground. The traverse was our dead reckoning. Every day the position of our camp was checked by observations for latitude and longitude, based on the Greenwich time of our chronometers. The rating of the chronometers was further checked by astronomical observations for absolute longitude, and by observations at intervals of five or six days based on difference of latitude and azimuths to known points behind us. This latter method was simple, and rendered accurate by the fact that our general course was north-west.

The compasses we used were small pocket prismatic compasses, reading to 1°; these we found to be very accurate and serviceable instruments. For purposes of comparison we also carried a large compass. Observations were frequently taken to find the variation of the compass, and the latitude and azimuth observations already referred to afforded a general check on the accuracy of our traverse both in direction and distance.

The pedometer we found to be far more accurate than was generally anticipated. The narrow and overgrown paths would have rendered the use of perambulators impossible, but by taking the mean of our three pedometers, each of which had its own personal correction, we found our results as regards distance wonderfully accurate. At frequent intervals, whenever we halted for a day or so, each officer checked his pedometer readings over a known distance, and, as I have said, the latitude and azimuth observations afforded a general check. We did not attempt to adjust our pedometers to our paces; this tends to make the screws loose and the instrument wanting in constancy. Instead, we found and allowed for the personal error of each instrument.

In the bush country it was a matter of some difficulty to get forward bearings, and as the African paths wind about a great deal, the mind was constantly kept on the stretch to make sure that the previous general direction had not been lost. The method of watching the direction of the shadows cast by trees, etc., suggested, I think, by Colonel Woodthorpe, R.E., proved a valuable method of determining when the general direction of the path altered to any great extent. As the caravan opened out and covered a considerable extent of road, the survey officer working at the rear of the column could, in the more open jungle, generally get a bearing some way in front on the head of the column. In very dense jungle we successfully tried bearings by sound. The surveying officer in rear called up the advance guard by drum signals; the advance guard then tapped their drum until the bearing had been obtained, and the officer in rear signalled he had got what he wanted. This method had to be used with caution if in the neighbourhood of hills or anything likely to cause echoes, but was found, after a little practice, to be surprisingly accurate.

Of the plane table work I need say nothing, as you are all familiar with it.

Our observations for latitude, time and azimuth were taken mainly with a 5-inch theodolite. We had also two sextants, one a 6-inch, and one still larger, in each division, and these were occasionally used by detached columns; but the theodolite is the more satisfactory instrument. By taking all observations in pairs, the second with the telescope reversed and turned through an angle of 180°, instrumental errors are cut out. Also there is the great advantage that, when shaky after hard work, or an attack of fever, the theodolite is the more satisfactory instrument. I should have preferred 6-inch theodolites, but could not get them at such short notice, so had to do with 5-inch. If possible, no theodolite smaller than this should be used, and the extra weight of the larger instrument is rarely of much moment. Of course, if you have to carry all your instruments on your horse you may do valuable work with a 3-inch theodolite, but on African expeditions you can generally manage to carry a larger instrument, and rarely have the opportunity of riding at all. Of course, the theodolite used should be a transit.

I need say nothing about the ordinary observations for time and latitude, but perhaps a few words on the latitude and azimuth observations may be useful. Suppose we start from a camp near which is some commanding peak, which is plotted on our map. We then march some 40 or 50 miles to the north-west, and find we can still see this peak. We take a careful latitude for our new camp, and an azimuth to our peak. The latitude of the peak is known, and hence the difference of latitude between the peak and our present position is known. The true bearing, irrespective of compass variation, is also known. From this the difference of longitude due to the known difference of latitude can be ascertained, and the true position of our camp be plotted relative to the peak. Thus the general bearing, the distance and the rate of the chronometers can be checked. As latitude can be obtained very exactly, and azimuth also, this is a very satisfactory method.

The more nearly north and south the general direction of the march has been, the more accurate the result obtained. When we were running east and west from the known peak we could not use this method, as the difference of latitude is small. For such cases we took the azimuth of the peak, and found its distance by chaining a base, and by triangulation with a theodolite, a fairly satisfactory but more troublesome operation.

Each division carried two watches, one by Dent, with a chronometer escapement, and the other with a watch escapement. I think this arrangement better than carrying two chronometers, for the following reason :—A chronometer escapement keeps better time than a watch escapement as a general rule, but it is far more liable to stop from a jar or even a rapid movement. The watch we found did not keep quite such good time, that is, its rate was more variable than that of the chronometer, but, on the other hand, it was not liable to stop.

The watch and chronometer were compared night and morning. Then, if during the march the chronometer stopped, either altogether, which is rare, or for a short time, which is more common, the comparison with the watch at night at once showed the error due to this, for the watch rate could not well alter much during the day. The chronometer was then started again, and a fresh comparison with the watch recorded. The more uniform rate of the chronometer checked the more irregular rate of the watch, while the watch guarded against errors due to the chronometer stopping.

It may be urged that a chronometer should be carried so carefully that it should never stop from any irregular movement on the part of its bearer. But many things in Africa are apt to cause irregular movements. Slipping on a wet rock, stumbling over a creeper or a tree trunk, being suddenly attacked by bees or ants, not to mention the occasional charge of a rhinoceros, may cause the bearer of this delicate instrument to make quick movements quite unforeseen by the stay-at-home critic.

Absolute longitude was obtained by observing the occultation of stars by the moon with a $2\frac{3}{4}$-inch telescope. This method, which is one of the most accurate the explorer can use, involves a great deal of calculation, and entails a good deal of patient watching with one's eye at the telescope, as it is difficult to forecast the exact time at which the phenomenon will occur. About 20 miles from Kampala, 780 miles from the coast, we were fortunate in getting a fine observation of the occultation of a star of the $2\frac{1}{2}$ magnitude by the new moon. As the star was near the zenith, and we were almost on the equator, two sources of error were reduced to a minimum, and we were gratified to find ourselves only three miles out of our reckoning.

The eclipse of Jupiter's first satellite affords a simple though somewhat inaccurate method of finding the absolute longitude. Though, perhaps, insufficient to base one's absolute position on, this method gives one an indication of any large errors in the rate of one's chronometer. We rendered the second method rather more reliable, perhaps, by always observing with the telescope immediately before or after the eclipse the great nebula of Orion. At the coast, with a known longitude, we had observed eclipses of Jupiter's first satellite, and on each occasion noticed into how many points our telescope resolved the nebula. We thus constructed a rough table of corrections, for the haziness or clearness of the night, which we could afterwards apply to render our observations more accurate.

In addition to the plan, a daily section of the route was also made to a horizontal scale of 1 mile to the inch, with a vertical scale of 100 feet to the inch. Heights were obtained by means of Elliott's surveying aneroid, which read to 5 feet. To render its work more accurate, we allowed for the diurnal wave, which was fairly constant. But to guard against variations in the diurnal curve, due to increased altitude and other causes, fresh diurnal curves were made out each time we halted for a day. In one district we found it advisable to use special precautions. This was in the meridional trough. Here we found that up to a certain hour in the morning the curve varied a great deal on different days, though after this hour it remained pretty constant. Hence, while working in those districts we had to commence work after this hour, and though this deprived us of the advantage of working in the cool of the morning, it mattered less at these comparatively high altitudes.

The altitudes obtained by the aneroids were not, of course, absolute ones, but this was a matter of lesser moment in a railway survey, as the relative heights were fairly accurate, and the relative and not absolute heights governed the grading of the line.

In the cases of hills which were off the route, or which we did not ascend, their heights were found by theodolite, and this practice proved of value by enabling us to check the constancy of our aneroids. For if observations for the height of a given hill from two widely-separated stations gave approximately the same altitude, we knew that our aneroids and the corrections applied to them must be fairly right.

Cross sections by Abney's level were taken at frequent intervals along the route each day, and enabled us to put in the contours on our daily maps. This, again, enabled us to judge of the curvature necessary for the railway, and of the amount of earthwork on different sections.

In addition to all these things came the notes on technical points. Thus we had to record the nature of the forest or jungle in order that an estimate might be made of the cost of clearing. The nature of soil had to be entered to enable us to ensure the proper rate for earthwork. Indications of the ground being waterlogged or swampy after rain had to be noted, as ballast was imperative at such places, and special catchment or other drains might be required.

At every watercourse we had to enter its width from bank to bank, the best site for a bridge, the nature and height of banks, the nature of foundations, whether special protective works would be necessary, the highest flood-marks, whether building stone or brick earth could be obtained near, and if there was water in the channel or not. For all more important streams natives were questioned as to the maximum floods known and any other points that might bear on the bridging.

At station sites there were also many points to record in addition to selecting a suitable site itself. The question of water supply, whether in case of streams direct pumping was possible, and in such cases whether one or more pumping platforms were required on account of the water level rising very high in floods. In cases where there was no river or stream handy, what arrangements were necessary for water storage and what length of delivery pipe would be required. Facilities fos the location of quarters for the railway staff, etc., on open line had also to be considered, and a number of other matters.

In addition to such purely technical work, we had to make notes on the population and attitude of the various tribes concerned, and carefully collect all information possible regarding the slave trade in those regions.

Altogether, as you can imagine, we had a good deal to do in the day's work. In each division the engineers took it in turn to run the actual traverse, and the head of the division had in addition the astronomical observations to take, and certain special points to note, as well as generally to supervise all arrangements for the marching, camping, feeding and protection of his men. The officer who ran the traverse generally commenced work about 7.30 a.m., for we had often to wait till that hour to allow of the sun being sufficiently high above the horizon for a time observation to be made. He got into camp at some hour between 3 p.m. and sunset, having made and recorded from 200 to 400 observations and notes. On arrival in camp he had to complete and transfer to the plane table the map of the day, and hurry out if necessary to use the plane table from some neighbouring high ground, though more often this was done by the officer off duty for the day.

The head of the division had also to take, if possible, an observation of the sun for time and azimuth. If, as was often the case, the rain and clouds obscured the sun, he had to observe the stars, or take observations of the sun next morning. In any case, he had to obtain his latitude from star observations, for we were so near the equator that we could not observe the sun on the meridian, as our theodolites were not fitted with astronomical eye-pieces. Sometimes latitude was obtained from the observation of a single star, but often north and south stars had to be taken. On many occasions, if the evening was stormy, the leader of the division had to get up during the night to see the stars and obtain his readings. In addition to this came observations for absolute longitude by Jupiter's satellite or by occultations, the latter observation necessitating various others, not to mention some pages of complicated calculations.

Take all this in consideration, with the facts that all ordinary military precautions had to be observed, picquets and sentries posted and seen to, men practised at alarm quarters every night, amongst tribes of doubtful character, arms and ammunition inspected, rations issued, sore backs amongst the donkeys looked to and treated, bridges built where necessary, and roads through the jungle and forest laboriously cut, ramps constructed at difficult ravines, and all the ordinary routine of a caravan attended to, and you will understand that the work was very heavy.

This was more especially the case when to our other discomforts was added an exceptionally rainy season, when day after day every man, after marching through wet grass and jungle, arrived in camp only to find that the ground was soaking, and often his kit too. The water was frequently bad, the food far from appetising, while on several occasions firewood was not to be obtained, and we had to subsist on half-cooked rations. Still, thanks to the energy displayed by all ranks, the work was successfully carried out.

I have shown, I trust, that the topographical work done was considerably superior to that usually resulting from a simple railway reconnaissance in India. The estimates were still more carefully worked out. I have mentioned that in an Indian reconnaissance the estimated cost of the proposed line is got from the experience of the actual cost of railways which have been constructed in similar districts in the same country. We were debarred from this practice in East Africa, as there were no railways existing. We had, accordingly, to start from the beginning.

The first point was to make out a schedule of rates, or the cost of a given quantity of different classes of work. This not only involved the wages of labour, but the cost of materials imported from England or obtained locally. I estimated that Indian labour could be induced to go to East Africa if offered pay at about three times what they would receive in the Punjab. The cost of materials from England was carefully calculated, and found to approximate closely to the cost of similar articles taken to India. An allowance had to be made for carriage of materials in East Africa, partly by the railway itself as it advanced, at what are called construction rates, and partly by local transport. I had enjoyed experience in India of scheduling rates for new works, and my schedules had been found fairly accurate, so I tackled the East African rates with some confidence, and calculated the cost of various items of work.

I understand that some critics have thoughtlessly challenged my figures because they hastily assumed that if the wages of labour are trebled, the cost of African work must be three times the Indian cost. This is, of course, quite wrong. Without going into great detail I may make this point clear. In the case of easy earthwork its cost varies very closely with the wages of the workman, as no materials are necessary. But in the case of quarrying the cost is composed partly of the wages of the workpeople and partly of the cost of blasting agents employed. Thus, as the cost of the latter item remains much the same in East Africa as in India, it is obvious that the African rate for quarrying cannot come to three times the Indian rate. This is still more marked in the case of concrete, masonry, ironwork, etc. Take the case of cement concrete, of which we may call the Indian rate unity. This is composed of 0·3 labour charges and 0·7 constants, cement, etc. The East African rate would be obviously the constant plus three times the labour charge, or 1·6 the Indian rate for cement concrete instead of three times the Indian rate, as these rash critics have hastily assumed. I could multiply instances, but I think this is sufficient to make my point clear.

Having made out our schedule of rates, we next made a series of type drawings for the proposed line. As the authorities had specified for a cheap line which would be sufficient to deal with the traffic for some time to come, it was judged permissible to make our sections for banks and cuttings, etc., a little lighter than in the case of mètre-gauge lines for India, which are designed for a heavy traffic. These drawings were made out, and from them we obtained the quantities for different works, which we tabulated as far as possible. Thus in the field the engineer had only to find out the average height of bank and cutting required over a short section and note the nature of the soil, when he could, from the tables we had prepared, obtain the quantity of excavation, and multiplying this by the rate obtained from the schedule, he got the cost of earthwork over that length. In one point we increased the Indian specification, viz., in the matter of earthen side and catchment drains.

Similarly, designs for bridges of different spans and heights were drawn, and the cost of each type calculated. A table was then made showing the cost of each type of bridge per foot lineal for a given height of bridge. Thus, in the field, the surveyor had only to note the height of bridge, the length from bank to bank—for we did not curtail the waterways, as is often done in Indian practice—and from these two factors he obtained the cost of the bridge. He had also to note if there was any difficulty about foundations or necessity for protective works in excess of those already provided for in the rate. As a matter of fact, the actual foundations, thanks to the proximity of rock, will prove much easier than we allowed for in our types. In addition to allowing for bridges over every watercourse, we estimated for additional openings per mile to facilitate the discharge of surface drainage, and to allow a margin.

For buildings, we similarly made drawings for different types, and obtained the cost per square foot. Then, by allowing each member of the permanent staff a certain area of house accommodation in proportion to his position, we obtained the cost of staff quarters, etc. Station buildings were allowed for according to the class of station, and provision made for the necessary engine sheds, workshops, etc.

The cost of the railway under other heads was more easily arrived at, and in every case we worked out and issued to the engineers concerned such data as was practicable, in order to facilitate work in the field and secure uniformity in estimating.

In all these estimates we took care to allow a considerable margin for contingencies and unforeseen expenses. Thus, in the original schedule of rates, about 10 per cent. was added to the actual rates as worked out. Again, in the type drawing the quantities were increased by 10 per cent. A further addition of 10 per cent. was made to the quantities as estimated in the field. Thus in some of the heads in the final estimate there was about 30 per cent. allowed for contingencies. The allowance was not so great on other items which could be more accurately forecast, such as permanent way, locomotives, and rolling stock, etc.

An additional provision for contingencies had also been provided since the estimate was submitted by the fall in the exchange value of the rupee. The estimate was a sterling one, and the large amount that represented the pay in rupees of the imported Indian labour was calculated at 15 rupees to £1. The exchange rate is now about 17 rupees, so that this has placed an additional sum of over £100,000 at the disposal of the engineer-in-chief for contingencies.

To arrive at the approximate cost of working the line, we had to calculate the annual expenditure by a careful consideration of the detail of *personnel* necessary. There was no other way that promised accurate results, as the initial traffic on the line would be so small as to render percentages based on Indian usage quite misleading.

As our orders were to estimate for a cheap, though workable, line, we had to economize in several ways. As there would be a difficulty about the water supply of stations in some cases, we placed our stations about 30 miles apart; this not only decreased the initial cost of stations, etc., but also decreased the annual expenditure to some extent. The engines were to be provided with special tender arrangements, to enable them to run the distance. As in many cases good building materials were scarce, and as in any case the cost of masonry or brickwork ran high, on account of the skilled imported labour it required, I proposed a large use of concrete and ironwork; the concrete required less skilled labour, and the ironwork, being made at home, required only to be erected in Africa.

For the actual line, too, we proposed certain expedients to cheapen its cost. Thus at several places, where we had to deal with escarpments and steps, I proposed double-engine gradients. This shortened the length of difficult work necessary. A double-engine gradient means that a pusher engine is detailed for that section, and helps the train up and down the steep double-engine gradients to the easier gradients above or below. In some cases the use of this steep gradient would not in itself have sufficed to obviate the use of tunnels, viaducts, and heavy retaining walls if the line was taken along the hillside, so reversing stations were proposed. By this means advantage could be taken of easy portions of the hillside, and heavy work be largely avoided. These expedients are not unknown in India, and are largely used in some other portions of the world.

The line we proposed was 657 miles long, and was estimated to cost £2,240,000 if ballasted only in swampy places; or, better, about £2,400,000 if ballasted throughout, but it was suggested that ballasting could be more economically done after the line was opened. Now £2,240,000 comes to £3,409 per mile. This agrees closely with some rough estimates made by eminent engineers. Sir Guildford Molesworth considered a light line, with 40lb. rails and no ballast, could be built for £2,700 a mile over the first 100 miles, but was not sure how far the conditions that governed this coast length would be maintained in the interior. Our estimate for this section, Mombasa to Tsavo, 123 miles, came to £2,930 per mile.

Sir John Fowler considered that with severe economy the average cost per mile would be £3,166, while General Williams considered that a line with a gradient of 1 in 60, and little or no ballast, and inexpensive bridges of wooden or iron trestlework, would cost about £3,400 per mile.

As I have said, our proposal for a line with 50lb. rails, iron trestle bridges and ballast only on swampy ground, and with a ruling gradient of 1 in 66, came to £3,409 per mile. But I was careful to point out that additional capital must be expended later on, to the extent of £2,200 per mile, to place the Uganda railway on the same footing as an Indian mètre-gauge line with moderate traffic. And, while advocating an initial expenditure of £2,240,000, I estimated the ultimate cost of the line, after improvements had been effected, would come to £3,685,000.

Before the construction of the line was commenced a Foreign Office Committee met, and came to the conclusion that my original estimate of $2\frac{1}{4}$ millions was too high. By reducing the weight of rail, and other economies, they brought the estimate down to $1\frac{3}{4}$ million sterling.

On actual construction being commenced another Foreign Office Committee, appointed to look after the work, apparently considered that $1\frac{3}{4}$ million was too little, and fell back on my estimate of $2\frac{1}{4}$ millions, but as they contemplated undertaking at once some of the improvements which I had suggested should be deferred until a later date, and apparently wanted a larger margin to work with, they asked for 3 millions. This, it will be observed, lies about mid-way between my estimates for the original light line and the same line after it had been completed on the basis of an Indian mètre-gauge railway with moderate traffic.

Various misleading statements have appeared in some quarters purporting to explain the increased estimate of 3 millions. It has been said that this is due to the weight of rail being increased from 37 to 50lbs.; but my original estimate was for 50lb. rails. Again, it has been said that our bridging was under-estimated, because the survey was in the field in a rainless year, when, as a matter of fact, we had exceptional rain. Another would have it that the detailed survey which has since been undertaken showed that our preliminary and approximate estimate was too low, when we find that, at the time the 3 millions were asked for, the detailed survey had only advanced 15 miles from Mombasa. As our first section, for which a separate abstract of estimate was shown, consisted of 123 miles, it was thus absolutely impossible for the detailed survey to say whether we had under-estimated or over-estimated the cost.

The real reasons that actuated the Committee in asking for an increased capital are probably the perfectly intelligible ones that they wished a large margin in hand, and contemplated effecting at once some of the improvements I proposed to allow to stand over until the line was built and its revenue increased.

Thus, at Mombasa I proposed to cross the creek, some 600 yards wide, which separates the island from the mainland, at a low level, and then, by means of a reversing station, gain sufficient length to enable the line to reach the top of the spur. This would have been a comparatively cheap solution, but, I understand, the engineers who are constructing the railway cut out the reversing station, and thus landed themselves in a difficulty, having in consequence to cross the creek by a long bridge at a high level. Their plan may be better than mine—that is a matter of opinion—but it is far more costly.

But these are questions that it is neither necessary nor desirable to go into at present. I have endeavoured to give you some idea of what we had to do and how we did it, and hope I have made the account sufficiently interesting without wearying you too much with technical details.

LECTURE II.

THE MAHOMMEDAN WARS IN UGANDA.

Although the Unyoro Expedition of 1893–94, of which I shall have something to say in my third lecture, is the only war in this portion of East Africa that has officially been recognized as active service, there have been other wars in Uganda which have witnessed far harder fighting.

Of such unofficial campaigns there have been several, the best known of which is, perhaps, the civil war between the Roman Catholics and Protestants of Uganda in 1892, when the latter triumphed, thanks to Capt. Lugard. There was Capt. Williams' expedition in boats against the hardy but piratical islanders of Nouma, an expedition which led to novel operations, and brought about a great fight on the Victoria Nyanza, in which 400 war-canoes and 10,000 combatants took part. There was Lugard's campaign against the exiled but powerful faction of Waganda Mahommedans in the spring of 1891. Lastly, there was the so-called Third Mahommedan War, in which I had the good fortune to command the forces of the Protectorate, and to finally crush the hostile Mussulman power in Uganda.

In addition to these larger operations, there was fighting in Usoga under Williams, and later under Grant, and some minor affairs in the south of Unyoro.

But all these unofficial campaigns had the one common factor that the officers in command were comparatively junior, and that the bulk of their forces were composed of irregulars, with only a small handful of trained men. The conditions that led to junior officers holding such responsible positions may easily occur again, especially in the case of Royal Engineers, who so often find themselves in out-of-the-way places. So it may be interesting to give a short description of the style of work we had in Uganda. Instead of selecting incidents from various expeditions, I propose to trace briefly the rise, struggle and fall of Mahommedanism in Uganda, as this introduces three separate campaigns, each arising from its predecessor. The first of these was a struggle in 1889–90 between the Christians and the Mahommedans, without European leaders or assistance on either side, and ultimately resulted in the victory of the Christians, who could, however, with difficulty hold the position they had gained. The second campaign, in 1891, was between the Christians, supported and led by Lugard, and the Mahommedans, backed by Kabarega of Unyoro. The followers of Islam, beaten in this combination, made a third bid for power in 1893, having gained Selim Bey to their cause, hoping that Selim Bey would carry all our Soudanese troops with him in his mutiny. Unfortunately for them, they showed their cards prematurely, with the result that they were beaten in detail, and given no rest till they ceased to exist as a political factor.

Before dealing with the military operations, we must consider shortly the nature of the country and its people, their political distribution and organization for war. For these are important considerations in all warfare, and perhaps still more so when we have to make use of large bodies of irregulars.

Uganda is a kingdom of 10,000 square miles in area, and is situated on the north and north-west of the Victoria Nyanza. Its physical configuration is peculiar. With the exception of a few districts, the country is a mass of small hills, rising about 600 feet above the general level, and separated by what appears a network of swamps, most of which are more or less overgrown with papyrus. These swamps are due to the fact that the fall of the drainage is so slight that the streams are too sluggish to prevent the growth of vegetation. The vegetation still further impedes the flow of the water, and the stream, though still flowing, forms a swampy bed, which may be anything from 30 to 800 yards wide, sometimes impassable, and at all times difficult to cross without a bridge or causeway. The banks of these swamps are generally bordered by a belt of forest or jungle, while the hillsides are more open, and the summits mostly bare. Dotted about on the sides of the hills are the banana plantations of the natives, and elsewhere, over nearly the whole country, is a covering of elephant grass, from 8 to 10 feet high. The coast of the lake is much more forested, and broken into many bays and indentations, which furnish, with the numerous islands which fringe the coast, very charming scenery. Part of Bulamwezi is more level, and covered with short grass, which supports plenty of game, and a portion of Buddu, too, is flat, but, in this case, more marshy than usual.

The people who inhabit this country belong to the great Bantu race, which extends north from South Africa. But in Uganda there is an admixture of blood, due to a comparatively fair-skinned people, which has come from the north-east, and is now known as Wahuma. The result of this intermixture has been very satisfactory, and the Waganda can only be classed as an exceptionally fine people, strong and well set up in physique, and at the same time intellectual and capable of rapidly absorbing and utilizing new ideas. Starting as a number of weak scattered chieftainships, they had gradually been welded into a united people by 30 generations of kings, and had extended their influence and authority over all the surrounding countries, until the territory that acknowledged the sway of Uganda covered some 30,000 miles.

This result had not been attained without numerous bloody wars, which had kept up a strong military spirit. The Waganda, when first visited by Speke and Stanley, were a people far in advance of the surrounding nations in organization, both civil and military, but their successful wars had made them cruel and arrogant. Like most native races in that part of the world, they were also very excitable, and this excitability, in spite of their shrewdness and intelligence, frequently led them into trouble, and caused a good deal of anxiety to the first Europeans who attempted to form an administration in the country.

The country was under a king, who, whatever his private character might be, was venerated by his people as the lineal descendant of the great Kintu, the founder of Uganda. He was assisted in the government by various officials, the chief of whom were the Katikiro, or prime minister, and the Kimbugwe, or chief chamberlain. Next in rank came the ten great chiefs who ruled the provinces into which Uganda was divided, and under them several hundred minor chiefs who governed districts. There were also a large number of officials directly appointed by the king in connection with the army, fleet of canoes, and royal household. With but few exceptions the chieftainships were not hereditary, and thus every peasant could hope to rise in the social scale by distinguishing himself in war, and every chief had an incentive to good work to avoid degradation. A regular system of court etiquette had grown up, and a recognized code of law, but this was often nullified by the despotic conduct of the king or great chiefs. Roads had been made and kept up, and markets were established at various centres under specified regulations and proper control. The revenue was drawn partly from taxes, partly from tribute from the surrounding states, and partly from forced labour on public works and government land.

But the Uganda organization for war will be more interesting to us. This was, for a semi-savage people, very well worked out. The military force of the country was divided into two sections. The first corresponded to a standing army, and consisted of a body of king's askasi; a certain number of these were permanently located at the capital, while the rest were distributed about the country on the king's numerous plantations. The standing force, when mobilized, was under the command of the Mujasi, a permanent official appointed by the king. The whole of the rest of the able-bodied males formed the second or feudal section of the military force. On the call to arms these assembled at fixed localities under the lesser chiefs, who moved their separate bodies of men to the provincial place of assemblage, and placed themselves under the command of the paramount chief of the province. A regular system of drum signals was understood, not only the call to arms, and beats for halting, marching, etc., but also personal signals for each of the principal chiefs.

So thoroughly had this been worked out that when the king sounded the great war drum at the capital, the whole country was under arms in 36 hours, for each hamlet had to pass on the signal without delay.

A Waganda army consisted of musketeers and spearmen, the latter forming two-thirds to three-quarters of the strength as a rule. To the spearmen fell the duties of foraging and transport, while the musketeers were the mainstay in battle. On the march a Waganda army moved in a number of parallel columns under their different chiefs, with, perhaps, one-third of the spearmen spread out like a fan to forage and gather information. The use of an advance guard was understood to some extent, but did not play a very prominent part on the march, as the foragers usually gave timely notice of hostile movements. On arrival in camp, each great chief took the section allotted to him by the general, and his sub-chiefs grouped their columns round him, but in no regular order. The spearmen who had been carrying food and stores now set to work, and in a very short time a great city of grass huts sprang up. These camps were often very crowded, and in the still evenings a great cloud of smoke settled down on them, and made respiration difficult, and also affected the mucous membrane of the throat and nose to such an extent as to produce something very like influenza. Sanitation was conspicuous by its absence, and it was not desirable to halt long at one place.

While the camp was being made the foragers scoured the country round and collected supplies for their comrades, and this had to be done daily, as the army only carried supplies for one or, at most, two days. This question of foraging materially affected the length of march. In well cultivated districts, where food was plentiful, the march was comparatively long, but in sparsely settled districts the foragers had such immense distances to travel in search of food that the main body had to make shorter marches in consequence. In the immediate neighbourhood of the enemy the supply of food became more difficult, so that when two hostile bodies got into touch they had to force matters to a conclusion or suffer from famine.

When drawn up for battle, the army formed a line of small columns, each led by a chief, and with the best armed men in front. Their attack was well delivered and very impetuous, the musketeers reserving their fire till they got to close quarters. But as they did not understand the use of supports and reserves, any check to the main attack frequently resulted in a retreat and subsequent panic. Men armed with breechloaders behaved well, standing their ground and firing, but those armed with muskets dashed in to close quarters, discharged their guns, and retired to re-load, so, as can be imagined, there was a want of cohesion after the first impetuous rush.

If the enemy were broken, the spearmen were let loose and pressed the pursuit most energetically, giving the foe but little chance of rallying. In fact, the musketeers decided the battle and the spearmen took up the pursuit.

Having thus glanced at the people and their organization, we will get to the business in hand, which hinges on the advent of the Arabs and Europeans. Certain Arabs from Muscat and the south coast of Arabia had long been settled on the east coast, and being energetic traders in slaves and ivory, had penetrated to Uganda and formed a trading settlement there. To the people of that country they were the representatives of a higher form of civilization and a nobler faith. A certain number of the people gradually began to embrace the religion of their trading friends, and when the first representatives of the Church of England entered Uganda in 1877 they found a small party of professed Mahommedans grouped round the Arab slave merchants. In 1879 the White Fathers of Algiers established a Roman Catholic Mission in the country, and all three sects began to gain converts. This was all very well in the days of Mtesa, who was a broad-minded, tolerant king, but the position was altered in 1884 when Mwanga ascended the throne. Mwanga, fearing the increase of European influence, which he heard was curtailing the dominions of the Zanzibar Sultanate, took the side of the Arabs and began to persecute the Christians. Bishop Hannington was murdered, and hundreds of native converts tortured and slain. Then, fearing in turn the Arab influence, Mwanga turned to the heathen, who were by far the most numerous party, and began a renewed persecution of Mahommedan and Christian alike. To such lengths did he go that these antagonistic factions were driven to act in concert, and in 1888 they combined to depose Mwanga and placed his brother Kiwewa on the throne. For six weeks all worked well under the new *régime*, and then the Mahommedans usurped the whole power by a cold-blooded massacre of the Christian chiefs as they issued from the king's durbar. The Christian party, deprived of their leaders, fled from the country, and Uganda was under the flag of Islam. As Kiwewa was a half-hearted Mahommedan, he was deposed to make room for his brother Karema. Thus 1888 closed with the Arabs and Mahommedans established in Uganda under a Mahommedan king, while Mwanga was in hiding at the south of the Victoria Lake, and the Christians were exiles in the neighbouring states.

Mwanga had meanwhile turned Roman Catholic, and the Christians began to rally round him in Usukuma, while a second body began to gain strength in Ankole. These two parties of Christians kept up communication through the friendship of a Baziba chief in the south of Buddu. This coming to the ears of Karema, he sent an expedition to punish this chief and isolate the two sections of Christians by preventing inter-communication, and by this action precipitated the great struggle of 1889--90. The Christians, though already planning an attempt to regain Uganda, were not yet ready, when they heard of Karema's expedition. Hastily assembling their force in Ankole, they marched into Buddu, intercepted Karema's army, and decisively defeated it in April, 1889. Flushed by victory, they advanced northwards, after valuable time had been wasted in hesitation, and on crossing the Katonga River found themselves face to face with a strong force which Karema had assembled to meet them. On the hills that overlook the swampy valley of the Katonga a great fight took place. At first the Christians seemed to gain ground, and pushed the Mahommedans back into some banana groves, but the Christian general fell, and his fall led to the retreat of his followers. The Mahommedans had, however, been so roughly handled that they were not in a position to pursue, and the Christian defeat was thus indecisive.

Meanwhile Mwanga, hearing of the first success, had decided to take the field in person, and in May of the same year he landed at Dumo in Buddu, and rallied the Christians round his flag. But before the Christian army could be properly organized the Mahommedans were upon them. Karema, furious that the Christians had been allowed to escape at the Katonga, had sent against them a force of 2,000 guns and some 5,000 to 6,000 spearmen. Against this Mwanga could only oppose some 1,100 musketeers, backed by 3,000 spears. A battle took place, the Christians were disastrously beaten, and Mwanga fled to Sese.

So far Karema had decidedly the best of it, in spite of the want of initiative his troops displayed after the battle of the Katonga, and the Christians were as much scattered and separated as if he had been successful in his first effort against the Baziba chief. Mwanga's chance of regaining the throne looked more desperate than ever, when an unlooked for event put fresh courage into the hearts of his followers. The heathen of the Sese Islands declared for him, and thus gave him command of the lake, as these islanders furnished the canoes and paddlers of Uganda. By June, 1889, Mwanga had collected a good many men, and embarking in the Wasese canoes, ravaged the coast of Uganda. Moving eastwards, he established himself on the Island of Bulingugwe, only some seven or eight miles from his former capital. Here he was safe, as the Mahommedans had no canoes, and the Christians, by frequent descents on unexpected points, harassed and weakened their opponents, while themselves steadily gaining in strength and warlike experience. This movement on Mwanga's part was distinctly a good one, as his proximity to the enemy's capital deterred Karema from sending any fresh expeditions against the Christians, who were again assembling in Ankole and Buddu. The latter, warned by previous failure, had selected as their general a brave and capable young chief, by name Apollo, and under his care were rapidly being organized for fresh efforts. The Christians were thus still separated into two main divisions, but this separation was rendered harmless, as, while Mwanga retained the enemy's forces at the capital, Apollo was free to collect and organize his army unmolested.

By September Apollo was ready to advance, having got together a force of 1,200 guns and some 3,000 to 4,000 spearmen; Mwanga had at his island headquarters about 1,000 guns with an equal number of spears; while Karema held Mengo with a force of some 3,000 musketeers and 5,000 or more spearmen. In addition to having an absolute superiority of numbers, the Mahommedan king had also the advantage of interior lines, while the division of the Christian forces, though harmless during the period of preparation, was a tremendous disadvantage when the time came to advance.

Apollo, convinced that nothing was to be gained from further delay, assumed the offensive, and when about three marches distant from Mengo met and overcame a small force Karema had sent to watch his movements. Karema's proper course was now to throw his whole strength against Apollo and crush him before he could be reinforced. Even if Mwanga had taken advantage of this to capture the capital he could not have held it for a moment had Apollo been driven out of the field. But Karema hesitated to do this, and adopting a middle course, divided his force and attacked Apollo with the larger portion while the smaller division guarded the capital. Apollo accepted battle, and the result of a fiercely contested engagement was indecisive, both parties falling back. Apollo sent to the king an urgent demand for reinforcements, as the result of the battle had shown that his force was too weak to attack Karema single-handed. Karema, by gross carelessness, allowed this reinforcement to reach him, and Apollo's strength was increased by 800 guns.

Apollo now advanced on the capital, and as he reached the Nalukorongo River was fiercely attacked by a superior force under Karema. The Christians held this position till nightfall, when the Mahommedans fell back on the capital, only about 1½ miles distant. Next day Apollo in turn assumed the offensive, and after hard fighting, in which the Arab colony took part on Karema's behalf, completely defeated the Mahommedans and captured Mengo. Karema and his beaten army fled north-west towards Singo, and were pursued for two days. The pursuit was then stopped, and Karema was thus allowed to rally his forces in Singo.

This decisive victory replaced Mwanga on the throne, and a short breathing space followed, while the offices of state were re-partitioned amongst the victorious Christians. Apollo, the successful general, was appointed Katikiro, or prime minister, a post he still holds with success.

As Karema's forces were now again making themselves felt, in

November, 1889, Apollo led an army against him. At a distance of 110 miles to the north-west of Mengo the Mahommedan army was found at Vumba. The position was a strong one on the summit of a rocky spur, with both flanks fairly well secured. Apollo could only deliver a frontal attack, and this he did. The Christians, with heavy loss, captured the spur, but Apollo fell wounded with a bullet through the shoulder. This caused the usual confusion, and the Christians retired. The Mahommedans pressed their advantage, and the Christian defeat developed into something like a rout. Mwanga hastily fled to Bulingugwe Island, and Karema was once more master of Uganda. It was not till February next year that the Christians were again able to resume a vigorous offensive. Karema was defeated, with a loss of some 800 men, and driven into Unyoro, and Mwanga re-entered his capital in triumph. This practically closed the First Mahommedan War, in which both sides fought unaided.

The representatives of the Imperial British East Africa Company now appear on the scene. At first they could exercise but a slight influence, but in December, 1890, Capt. Lugard got the king to make a treaty placing Uganda under the Company's protection. Meanwhile Karema, aided by Kabarega of Unyoro, was devastating the border provinces, and even raiding within sight of the capital, so in April, 1891, Lugard took the field against him. His force consisted of four Europeans, 300 drilled soldiers, 300 armed porters in the Company's service, 4,700 Waganda musketeers, and 12,000 spearmen. With this formidable force he advanced slowly to the north-west, his marches averaging 5·9 miles a day. The season was unfavourable, as it was in the middle of the rains, and the crops were not ripe. To add to his difficulties, the country through which he marched had been devastated by the enemy, and food was scarce. He had not cloth enough to properly clothe his men or furnish them with tents, thus increasing their hardships. After travelling some 140 miles he came into touch with the enemy strongly posted on the opposite bank of the Kayangora River, which was unfordable. To build causeways and force the passage by a direct attack seemed too hazardous, especially as the Mahommedans were reinforced by 1,300 Wanyoro guns. Lugard had accordingly to manœuvre. With the bulk of his force he proceeded to build causeways across the river as if he intended to force the passage, while a strong detachment of 2,000 guns commanded by Apollo made a flank march in the morning mist under cover of a hill and crossed the river higher up. Once Apollo was safely established on the enemy's bank, Lugard broke off his bridging operations, and by a rapid march joined his detached body. The Mahommedans, completely outmanœuvred, retired to a rocky hill and took up a fresh position. Here Lugard attacked them. He placed the Waganda in first line, and his own men in second line, in rear of the centre as a support He had a Maxim, but as the ground was not favourable for its use it was not brought into action. In this formation the Christian army advanced. The left wing was checked by the Mahommedans, and Lugard moved to support it, but meanwhile the centre and right wing drove the enemy off the ridge. The Wanyoro bolted, and the Mahommedans, after a stubborn resistance, retired in disorder. The Christians pursued and drove them nearly to the Kafu River.

Lugard, with correct military instinct, was in favour of an immediate advance on Kabarega's capital, but was met by an unexpected opposition on the part of his Waganda. The latter had already been on short commons in the devastated country they had traversed, and had suffered greatly from the incessant rain. Small-pox had also broken out in the army, and altogether they did not feel desirous of entering on a fresh campaign against Unyoro. They pointed out that three great rivers, all impassable after the rain, lay between them and Kabarega's capital, and that one of them was a very formidable obstacle, being nearly 1,000 yards wide. They also laid stress on the fact that there was no food ahead, and that the force would starve if it advanced. We afterwards found out that the obstacles to an advance were by no means so great as they were painted, but Lugard did not know this, and accordingly abandoned further pursuit, broke up his forces, and returned to Uganda. The expedition had been carried out in very unfavourable circumstances, but by Lugard's skilful tactics the enemy's power had been completely broken for the time being by one decisive victory. But as the pursuit was abandoned, they were given an opportunity of re-assembling and making themselves felt again later on.

We must now glance rapidly at the events that led up to the third and final Mahommedan effort. After his expedition against the Mahommedans, Lugard led an expedition to Kavalli's, west of Lake Albert. There he found a colony of some 9,000 Soudanese, men, women and children, established under Selim Bey, one of the officers who had rebelled against Emin Pasha, and who had been abandoned in Equatoria by Stanley, who obtained proofs that Selim Bey intended treachery. Lugard prevailed on Selim Bey to bring his followers to South Unyoro, where they were located in a chain of five forts, running nearly north and south, and protecting Toru and Usongora, fertile states on the slopes of the snow-clad Ruwenzori. Lugard took back to Uganda 1,000 men, women and children, and from them raised a new company of Soudanese soldiers. The remainder of the Soudanese garrisoned the forts pending orders from Egypt as to their final destination, and meanwhile raided Kabarega's outlying provinces.

Lugard had only been three weeks in Mengo, when in January, 1892, civil war broke out between the Roman Catholics and Protestants. This split amongst their quondam foes seemed the Mahommedans' opportunity, and they were quite alive to the fact. They could not, however, decide what to do. One party advocated an immediate advance into Uganda with Kabarega's assistance, another that an alliance should be formed with Selim Bey's men, their co-religionists, preparatory to attacking Uganda. The latter counsels prevailed, and negociations were opened with the Soudanese. The Soudanese, however, regarded the Waganda Mahommedans with some suspicion as the allies of Kabarega, who had attacked the Unyoro Forts, and the Mahommedans found they had wasted time to no purpose, and had, moreover, alienated Kabarega's friendship. They accordingly moved into Uganda. Their advent caused considerable consternation. Lugard sent Dualla and Selim Bey to meet them and negociate, and followed himself in person. The negociations were difficult and delicate, but finally he succeeded in gaining what he considered a satisfactory settlement. The Mahommedans were granted three of the smaller Uganda provinces on condition that they settled down peaceably and handed over to Lugard their Sultan, Mbogo, who had succeeded Karema, and the young prince, Karema's son. The Mahommedans said that they surrendered to Lugard and not to Mwanga, and that Dualla and Selim Bey were sureties for Mbogo and their prince. Shortly after this settlement Lugard and Dualla left for the coast.

The geography of Uganda was very imperfectly known at this time, but the fact remained that the hostile Mahommedan faction, which had been expelled by the Christians after much bloodshed, although their numbers had dwindled down till they formed, perhaps, one-twentieth of the population, had got three out of the ten provinces of Uganda. This meant land and power far in excess of what their numbers entitled them to. Had they loyally adhered to their agreement and settled down in peace all would have been well, but they soon started intriguing and plotting to increase their power. They even went the length of inciting the Roman Catholics to join them in upsetting the Company's administration and ousting the Protestants, but the Roman Catholics declined their overtures. The Mahommedans then began to assiduously cultivate the friendship of the Soudanese soldiery and of Selim Bey.

Captain Williams, R.A., was now at the helm in Uganda, and though the country generally was enjoying increased prosperity under his leadership, the Mahommedan problem became more and more menacing. It will be seen from the map that the three Mahommedan provinces* formed a compact group, which more or less separated the Roman Catholics from the Protestants, and which also lay between the Unyoro Forts and the garrison of Uganda, which was at this time concentrated at Mengo. Round the Mahommedan borders dacoities were of frequent occurrence, so much so that the neighbouring districts of Singo and Mawakota were almost deserted. Not only were the Mahommedans responsible for these dacoities in Uganda, but they indulged in a certain amount of slave raiding outside its borders, and induced some of the Soudanese in the Unyoro Forts to join them in these malpractices. Indeed, we afterwards discovered that there was a regular slave market at one of these forts. Williams had one dacoit executed at Mengo, but this did not have more than a temporary effect, and in the winter of 1892 there was very nearly war. After a more than usually daring dacoity, Williams demanded the authors of the outrage. The message was more or less of the nature of an ultimatum, threatening hostilities if the guilty persons were not handed over within a specified period. The Mahommedans took no notice of his threats, and at one time it seemed that there was no course open to Williams but to lead an expedition into their provinces. But Mbogo and Selim Bey now came forward. Mbogo urged his co-religionists to meet Williams' terms, while Selim Bey, hinting that his Soudanese troops would not fight against their co-religionists got Williams to extend the limit specified in his ultimatum. The result was a compromise, the Mahommedans partially fulfilled the terms, and the matter dropped. The followers of Islam now leant more and more on Selim Bey, who was a vain old man with a great idea of his own importance, and increased the strength of the small colony they had formed at the capital. Thefts and

* Butambala, Busuju and Butunzi.

outrages were of frequent occurrence, and on one occasion there was nearly an outbreak. One Sunday morning the bugles in the Fort sounded the alarm, and the garrison fell in under arms. On every side the Christians could be seen assembling in armed bodies, and hastening towards the Mahommedan quarter, where there had been a serious disturbance, resulting in the burning of some Protestant buildings. Williams and I went at once to Natate, and found both parties armed and ready for war. Williams, however, restrained the Protestants, and after some trouble secured one or two of the Mahommedans, who had been concerned in the outrage. For several days the tension remained, and there were frequent alarms, but finally peace was secured. The Mahommedan party, however, still declined to fulfil their obligations towards Mwanga, and there was a growing distrust in the land and fear of a rebellion.

At this stage a new figure appears on the scene in the person of Sir Gerald Portal, who arrived with a talented staff to settle the question whether Uganda should be retained or abandoned. He decided that we must retain the country, and then set to work to tackle the three problems of the hour. These were the Roman Catholic, Soudanese and Mahommedan questions. After Lugard's civil war, the beaten Roman Catholics were confined to Buddu, and though they had loyally adhered to the terms of their agreement with Lugard, they were sullen and dissatisfied, and complained that the territory allotted to them was insufficient. Sir Gerald Portal, seeing that a reconciliation between the Christian parties was essential for the prosperity of the country, after delicate and prolonged negociations, arrived at a settlement. The Roman Catholics were given additional territory and were satisfied.*

The Soudanese question was somewhat different. I have already mentioned that Lugard had located these in a line of forts in South Unyoro, only raising and taking to Uganda one company. Williams had enlisted a second company, which answered well. These two companies and the original force of Soudanese, which Williams had brought from Egypt, formed the Company's troops in Uganda. When the Company's flag was replaced by the Union Jack, and

* The Roman Catholic territory by this arrangement included Buddu, Mawakota, the large island of Sese and the district of Bwekula. They were also given a narrow strip of land connecting Mawakota with the capital, and additional properties at the capital itself. They gave up a small island, Lulamba, and a few shambas in Busiro.

Williams left for the coast, he took with him the old company of Egyptian Soudanese men who had no connection with Selim Bey, and who could be depended on in all circumstances. It was proposed to raise fresh troops from the Bey's men to replace them. But there was another consideration. The Soudanese in the Unyoro Forts were not in the Company's pay, for the Company's representatives had not the wherewithal to pay them. They had not even the means to ration this crowd of wild soldiery, amounting, with their wives and families and followers, to some 6,000 souls. Lugard had accordingly authorized the garrisons of the forts to feed themselves by raiding the common enemy—Kabarega of Unyoro. So literally had this been interpreted that the Soudanese had devastated some 1,500 square miles of country, and alienated even the friendly sections of South Unyoro. Terrible stories of atrocities filtered into Uganda, and though these were, as usual, greatly exaggerated, Sir Gerald Portal had to take into consideration measures to curb the licentious soldiery. He decided to effect this end by enlisting and bringing under discipline a larger proportion of them than was strictly necessary to garrison Uganda.

Now Lugard had estimated that 500 soldiers would suffice for the country if divided amongst several forts, and Williams was of opinion that the minimum requirements were 300 men concentrated at Mengo. As Sir Gerald Portal had founded a new station at Port Alice, I asked for 350 men for duty in Uganda itself. Sir Gerald decided to raise 600 men, of which 350 were to be at my disposal in Uganda, while the remaining 250 held the Unyoro Forts. I may mention that Sir Gerald was not himself in favour of retaining South Unyoro, but on the representations of Williams, Major Owen and myself, agreed to do so, if it was possible with 250 men. It was out of the question to hold all four forts—three of Lugard's original forts had been abandoned, and two new ones built—so Owen, who was sent to Unyoro, had orders to evacuate the two northern forts, and concentrate on the two eastern ones with a detached post towards Toru. Selim Bey raised difficulties, as he considered the garrisons too weak, and was in favour of the whole of his men being brought into Uganda. He was at this time in a dissatisfied frame of mind, having recently heard that the Egyptian Government declined to have anything to do with him or his men, as they had mutinied against their Governor, Emin Pasha.

Owen was accordingly sent to Unyoro with Captain Raymond Portal and Mr. Grant to enlist and organize the Soudanese force.

There were also a large number of unenlisted, amounting to over 2,000, and containing some 400 more or less fighting men, and many old officers. Some were not enlisted because of age, and others because they were of bad character. Sir Gerald gave Owen orders to send them into Uganda, where they would be assigned land. This was a point on which Selim Bey laid great stress.

In due course Owen reached Unyoro and raised the necessary force. A strong company, with a few of the unenlisted, was at once sent into Uganda, but the difficulties attendant on moving, feeding and settling the body of some 1,500 people led Sir Gerald to send counter-orders to Owen, directing him to retain the rest of the unenlisted in Unyoro until arrangements could be made for their reception. It took 15 days for these orders to reach Owen, and in this time that energetic officer had already sent off the unenlisted towards Uganda. All he could now do was to halt them at the Eastern Unyoro Forts. Round these two forts there was little food, and the advent of some 2,000 extra mouths caused great scarcity, and a good deal of dissatisfaction.

Leaving Owen and his assistants busily engaged in Unyoro, let us return to the state of matters in Uganda. Selim Bey was much put out that all the unenlisted had not been brought into the country, and took up an attitude suggestive of future trouble. Sir Gerald Portal wished the few unenlisted whom Owen had sent in located at his new station at Port Alice, but Selim Bey desired them settled at the capital, and flatly refused to allow them to proceed to the former station. His argument was that we could do as we pleased with the enlisted soldiery and their families, and he, as commandant of the Soudanese Battalion, would see our orders carried out, but that we had nothing to do with the unenlisted, who remained under his sole command as heretofore. Sir Gerald Portal did not deal with this unexpected development as firmly as he might have done; a dangerous compromise was effected, and the matter allowed to drop.

Sir Gerald Portal having thus disposed of the Roman Catholic and Soudanese problems, proceeded to take up the Mahommedan question, to which he attached less importance, as the followers of Islam formed the weakest of the three Uganda factions. They had seen the Roman Catholics receive an extension of territory, and now claimed an increase for themselves. Their minimum demand was for the rich province of Busairo, and without this they declined to pay their taxes or fulfil their obligations towards Mwanga, the king of the country. To emphasize their demands they took up an independent attitude, and caused frequent disturbances at the capital, resulting in several murders.

Selim Bey also took up their cause, and not only sent an escort of his men with certain Mahommedan chiefs to intimidate the king, but wrote to Sir Gerald Portal supporting the Mahommedan claims. The Imperial Commissioner had already informed this party that its claims to fresh territory were inadmissible, and announced that he would hold a final durbar to settle matters. He was now in the midst of sore domestic affliction, for his brother Raymond, who had become seriously ill in Unyoro, had reached the capital only to die. This was a sad and unexpected blow to Sir Gerald, who was himself in a poor state of health after frequent attacks of fever. Fearing a complete breakdown his staff hastened their preparations for departure, but on the day before he left for the coast Sir Gerald pulled himself together and held his promised durbar. To prevent all chance of misunderstanding, Mr. Pilkington, of the C.M.S., a distinguished Kiganda scholar, was asked to act as interpreter. The durbar proved a surprise, for the Mahommedan chiefs openly threatened rebellion if their claims were not met. Had Sir Gerald then and there arrested the rebel leaders the storm might have blown over, but instead he warned them against rebellion, and informed them that he had left me orders to deport any chiefs who attempted anything of the kind. Next day Sir Gerald left for the coast, and the charge of the temporary protectorate fell on my shoulders.

On the conclusion of the durbar the Mahommedan leaders visited Selim Bey, but it was not till later that we learned what had taken place at this interview. The chiefs urged Selim Bey to make a last effort in their favour before the departure of the Imperial Commissioner, but the Bey advised them to have patience. He pointed out that with Sir Gerald departed his independent escort of Zanzibar troops, and that the garrison of Uganda in future would consist of the Soudanese who had followed himself from Kavalli's. Once the Imperial Commissioner and his escort were well away, matters would be much simpler. If the Europeans still refused the Mahommedan claim, nothing would be easier than to arrest them in their beds some night, and dictate what terms they pleased. Meanwhile the Mahommedans were to concentrate at the capital, and quietly make their preparations for the coming *coup d'état*.

We must now return to Unyoro, where affairs had assumed a serious aspect. A large force of Manyema slave traders had settled on the frontier of the Congo Free State, and built a stockaded station on the Semiliki River. From this they raided Usongora and carried off a number of slaves. Our small garrison at Fort George had sallied out to assist the natives, and had been roughly handled. Owen proceeded to Fort George, and sent envoys to the Manyema, warning them to desist from attacks on territory now under the British Government, but his envoys had been made prisoners, and his threats were ridiculed. Owen also got hold of two letters written by these slave dealers. The first was a defiance to the Commandant of Fort George, the other appeared to be addressed to the Waganda Mahommedans, and encouraged them to hold out against the Europeans, as the followers of Islam had swept all before them on the Congo, and would soon come to the assistance of their co-religionists.

Owen's force was small, and he could do nothing at the time, so, leaving Fort George, he made his way across Kitakwenda to the eastern forts, being attacked and harassed by the natives *en route*. At the forts things were very bad. Kabarega of Unyoro had sent an army against them, which, though it had failed against the forts themselves, had severed the communications and stopped the food supplies. Bimbashi Shukri Aga had led a small force against the Wanyoro, but had fallen into an ambuscade and been defeated. Shukri himself was killed. Owen at once took energetic measures to re-open communication with Toru, and fed his starving garrisons, and at the same time wrote to me for reinforcements. He asked that his despatch should be sent on to Sir Gerald Portal, as he wished him to understand the difficulty of the position in Unyoro, which he considered Sir Gerald had all along under-estimated. In forwarding this despatch I gave an account of the attitude of the Mahommedans and of Selim Bey, and detailed the measures I proposed to relieve Owen. In reply to this Sir Gerald, who had recovered his health from camp life, wrote to say that, in view of the serious state of matters in Uganda and Unyoro, he would delay his departure to the coast till he heard further news, and intimated his wish to return to Uganda should an outbreak take place.

Meanwhile the situation had altered. The Wanyoro army had retired before Owen, and that officer was only awaiting reinforcements to proceed against the Manyema. But in Uganda the Mahommedans had become more defiant, and Selim Bey, whom I had sent to Port Alice for change of air, had, after looting a C.M.S. station by way of pastime, forbidden the unenlisted and some of the troops at Port Alice to obey the European in command. He had also ostentatiously hoisted the Mahommedan flag. But before I could bring him to book for this misconduct the crisis developed, and he had more serious things to answer for. I had already warned Owen that an outbreak was imminent, and this was fortunate, as none of my subsequent letters reached Unyoro.

As it was impossible to allow the Mahommedan attitude at the capital to continue, the king had held a durbar, at which the chiefs were called upon to submit and become peaceable subjects. The rebel leaders temporized, and meanwhile sent word to Selim Bey, who promptly took action. He sent me a message by his confidential sergeant, through whom he had communicated with me on other occasions, that if the king and Christians attacked the Mahommedans he would consider it hostile action against himself, as he was surety for Mbogo and his people.

This message reached me on the afternoon of the 16th June, and my eyes were now open to the gravity of the situation. There had all along been rumours that the Soudanese would make common cause with the Mahommedans, but we had laughed at such tales. Now the Bey had thrown off the mask. I had to remember that I had to deal with a man who had already been concerned in one successful mutiny against his Governor—the unfortunate Emin Pasha—and a man whose influence over his troops was supposed to be great, while he himself claimed absolute control of the large body of unenlisted, but armed, Soudanese.

The troops might, or might not, follow his lead; in any case they were distrusted by the Christian natives, who must form my main strength in case of trouble. The Roman Catholics were, for the most part, too distant to be of much service, and the Protestant chiefs had again and again assured me that their followers would not stand for a moment against a combination of Mahommedans and Soudanese, and would probably flee at once should the rumours of such a combination be confirmed. Owen and Grant were isolated in Unyoro with 250 Soudanese and a strong force of unenlisted and discontented men, who were known to be in close correspondence with Selim Bey. The Bey was at Port Alice, and might be supposed to have complete ascendency over the 250 rifles at that station, as his orders against the European Commandant had been obeyed. There were two Europeans, civilians, at the same place, with about 150 Swahilis, many of whom were sick. At the capital I had two civilian assistants, with 70 Swahilis, and a company of Soudanese.

Lieutenant Arthur was in Usoga with a half-company of Zanzibar troops, some six to seven days' march away.

The Mahommedans, on the other hand, had about 1,000 guns at the capital, and more in the provinces, and were already assembling for war. If the Bey could get possession of the fort at the capital, with its 400 reserve Sniders and stores of ammunition, he and the Mahommedans could sweep the country.

My only chance seemed to lie in a rapid initiative, which would dislocate the rebel plans, and, perhaps, save the situation.

This I resolved to take, and till a late hour on the night of the 16th I was busy sending out orders to the different stations, and information to the various missions whose safety I had to consider. The Bey had orders to stand fast at Port Alice and guard the stores. This order was communicated to him in a public manner, as, though I knew I could not depend on Selim Bey, I thought the publication of such an order might cause hesitation and discussion amongst his followers, and thus gain us a little time, which was of the utmost importance. The Europeans at that station were to join me at once with all the Swahilis. Owen was given general instructions, and Arthur was ordered to join me by forced marching, while his European assistant concentrated the small force in Usoga on the Nile to keep open our communications with the coast.

On the morning of the 17th I informed the Mission stations of the new development, and gave them the option of seeking safety in flight, or of joining me, which was the wiser course. One and all agreed to stand by me. I had also warned the Katikiro to quietly and unostentatiously assemble a strong Protestant force in the capital, and this had been done. I now told him of the Bey's attitude, and that I meant to take the initiative, but this intelligence was not to be promulgated, as we both feared the Protestants would refuse to face the Soudanese-Mahommedan combination, and seek safety in flight. I expected the Europeans from Port Alice, 21 miles away, on the afternoon of the 17th, when we were to commence operations. In the afternoon all the missionaries assembled in the fort, dropping in by twos and threes, and we scored the first move by arresting two of the rebel chiefs, who were found in consultation with Selim Bey's representative. The Soudanese Company professed loyalty, but declined to take the oath of allegiance to Her Majesty on the Koran, *as they did not know what might not happen.*

My reinforcements from Port Alice not having arrived, I had perforce to be satisfied with this, as I had not sufficient force to do otherwise. As the afternoon wore on, and there were no signs of the approach of the Europeans from Port Alice, our uneasiness increased. But I had to do without them, so set off for the Mahommedan quarter with a small escort, to endeavour to get hostages for their good behaviour. I got one chief, and was promised another next morning, and the Mahommedans agreed to lay down their arms next day. This was only a blind, as they at once sent off word to Selim Bey to hurry to their assistance, and, meanwhile, drew in reinforcements from the provinces.

Early on the morning of the 18th the Europeans and Swahilis arrived from Port Alice. They had been delayed for various reasons, but had at length reached us with the grave intelligence that Selim Bey had informed them, before their departure, that if I did not make peace with the Mahommedans, he and all his men would join their co-religionists. There was now little time to waste. I calculated that the Bey could not reach the capital until after 1 p.m., so the Mahommedans must be dealt with before that hour. But first of all the Soudanese troops must be disarmed.

This step was unavoidable. I could hardly think that the Kampala company of Soudanese, with whom I had been so intimately connected, would of themselves take an active part against me, but should the Bey and his follows reinforce the Mahommedans before we could defeat them, I might say, in the words the Soudanese themselves used when refusing to take the oath of allegiance, one did not know what might not happen. One thing was certain. The Protestant Waganda, who formed my principal strength, would not venture to face the Mahommedans as long as they were liable to an attack in rear by the Soudanese of Kampala. In the past each soldier was allowed to keep in his hut his rifle and 40 rounds of ball ammunition, and my first duty was to call in and secure in the fort the arms and ammunition.

The Roman Catholic missionaries had fled during the night, but the gentlemen of the C.M.S. repaired to Fort Kampala, where they and the Swahilis were armed and told off to various posts. The Katikiro was instructed to have several small columns concealed in the plantations near the fort, to overpower the Soudanese if they mutinied. The latter were ordered to fall in on the glacis, which they did. The Soudanese guard was then relieved by Swahilis, and I personally marched the old guard on to the parade ground. Here I told the company of the Bey's conduct, and, in view of the refusal to take the oath of allegiance the day before, asked which side they intended to take. Meanwhile, the parapet behind them had been manned by Europeans and Swahilis, and two maxims were run out to cover their flanks. The Soudanese said they would follow me, and while I congratulated them on their decision, I said I must call in the arms for the time being. They then grounded arms and marched off. The arms were tied in bundles by a party of unarmed Swahilis, who were told off for the job, and taken into the fort. The ammunition was also called into store. The native officers retained their swords, and a few rifles were issued for a picquet on the lines. To the intense surprise of Europeans and natives alike, the Soudanese had been disarmed without bloodshed, and the Christians, who had before been terribly despondent, were now ready to follow us anywhere.

Mbogo and the young Mahommedan prince were already in the fort under a guard, and I now cleared out his following. Those who surrendered their arms were admitted to the fort, the others were passed through our lines and allowed to go free, as I had still a lurking hope that the main body of the rebels might give in when they saw we were in earnest.

The Protestant forces at my disposal, amounting to some 7,000 men, with over 2,000 muskets, were already, in accordance with my instructions, holding the ridge from Rubaga to Namirembe, 500 guns being posted in support in rear of the centre. Behind these again were the reserves. A few hundred guns on the King's Hill, in rear of the left, and the 10 Europeans, 8 trustworthy Soudanese, and about 150 Swahilis holding Fort Kampala in rear of our right. Both Maxims were ready to support our first line should the enemy break through.

Our position formed an irregular crescent, and on a lower hill, between the horns of this, was massed the rebel force of several thousand men, with about 1,300 guns.

Rubaga, the dominant point on our left, extended to a difficult swamp and covered the direct road from Port Alice, along which the rebels expected Selim Bey to advance to their assistance.

The rebel Mahommedans were now informed that they would be attacked at one p.m. precisely if they had not laid down their arms before that hour, as they had fulfilled none of the promises made the evening before.

The Mahommedans had planned their outbreak for the 19th, and had not yet received their final reinforcements from the provinces, and they saw that victory was slipping from their grasp unless they could gain time to allow of the Bey's force joining them. As one o'clock approached and they found they could not waste more time by pretended negociations, they resolved to take the initiative. If they could capture Rubaga by a sudden attack—and they not unnaturally thought that the Protestants would have their main force on Namirembe round the C.M.S. station—they would have secured a position that covered the Port Alice road, and might hold out till reinforcements reached them.

Just before one they feinted at our right and delivered an impetuous assault on our left. The Mahommedan columns at first gained ground, and had got within a few hundred yards of Rubaga, when our support entered the fray and checked their advance. Reinforcements from our right now moved across to help the hard pressed left, but the vigour of the Mahommedan attack had passed, and when their general fell dead they retired. The Christians pressed them hard and drove them into the swampy river, crossed with the fugitives and converted the retreat into a rout. Selim Bey had meanwhile sent a force from Port Alice, but this had barely got half-way when it heard of the Mahommedan defeat, and retired.

My intention was to lead a force against Selim Bey immediately after defeating the Mahommedans at the capital, but the body of natives told off for the purpose, Waganda-like, joined in the pursuit, and on the morning of the 19th I had barely 200 men available. That afternoon the victorious army returned, and early on the 20th I led a force of 4 Europeans, some 8 Soudanese, 40 Swahilis and 700 Waganda musketeers, with twice that number of spearmen, against Port Alice. By 3.30 p.m. we were drawn up ready to assault the Soudanese position. I adhered to the Waganda order of battle, but told off Europeans to lead the right, left and centre, while the fourth European covered the advance with the Maxim. All being ready, I determined to give Selim Bey a chance of surrendering, and advanced with 6 men and the flag. A deputation of officers met me half-way, and the Soudanese surrendered and gave up their arms.

In three days' sharp work we had thus overcome two bodies of the enemy by catching them in detail before they could combine. Selim Bey was tried, reduced and deported to an island for safe keeping, and I had time to take measures to assist Owen, who was in a very precarious position in Unyoro.

A message was sent to the Mahommedans that all who wished peace, or who had not been mixed up in this trouble, should repair to Busuju, where their neutrality would be respected, and meanwhile a force of 7,000 Protestants was dispatched to pursue the rebels, who had retired towards the Unyoro Forts, and Lieut. Arthur was sent to Buddu to restore confidence there and hurry up a Catholic contingent of 3,000 men who were to join the movement against the rebels, and in support of Owen.

The unenlisted Soudanese had meanwhile plotted to join the rebel Mahommedans, assassinate Owen and Grant, and form a Mussulman state in Toru. The beaten Mahommedans had reached the forts, and were in communication with the disaffected, while terrible stories of the atrocities I had committed in Uganda were circulated. Amongst other things I was reported to have massacred all the Soudanese, without regard to age or sex. Owen was in great danger, for the army I had sent to his assistance had not yet arrived. He, however, extricated himself from his difficulties by a bold and hazardous expedient, which, however, proved successful. He called up the ringleader of the disaffected Soudanese, told him what he knew of the state of affairs in Uganda, pointed out that the Mahommedan outbreak had been beaten, and finally placed him in command of the forts, with an assurance of his perfect faith in his loyalty. Belal Bey, who was in Selim's secrets, saw that the rebellion had collapsed, and that he might now save his own skin by Owen's unexpected action. He accordingly deserted the cause of Islam and became a warm supporter of British authority. The disaffected Soudanese, paralyzed by the desertion of their most powerful leader, followed suit, and the Soudanese mutiny collapsed. The Christian army now arrived on the scene, and the Mahommedans, after deceiving Owen and the Christian chiefs by pretended negociations for peace, retired westwards to join the Manyema. Owen, at the head of the Christian army, pursued, and in the neighbourhood of Kivari's overtook and defeated the rebels with great slaughter. The Mahommedans, having lost in action their most warlike chiefs, were now glad to make peace, and accompanied Owen back to Uganda to stand their trial for rebellion. But once back in their own country they gave Owen the slip and proceeded to occupy by force their former provinces.

These provinces were no longer theirs, for I had meanwhile followed the example set by Lugard and Portal, and gone in for a little re-distribution of territory on my own account. Butambala had been given to the section of Mahommedans who had accepted my offer of peace made after the surrender of Port Alice, and Butunzi and Busuju had been handed over to the Protestants and Roman Catholics respectively. The re-distribution had been thus early effected as I wished to bring it home to all that rebellion was not a game that could be played with impunity. In accordance with this re-distribution of the former Mahommedan provinces, their new owners had entered into possession, and these new owners were now being ruthlessly expelled by the rebels who had deceived Owen.

This could not be tolerated, but the Christian army, which had fought our battles for us, had been disbanded after Owen's success at Kivari's, and it would take time to collect another. So I ordered Owen to move south from Matiana, the Makwenda's headquarters in Singo, with 100 Soudanese and some 200 Waganda guns, which were immediately available, to protect Busuju, while with a similar force I moved west from Kampala to help our friends in Butambala. In four days we were within supporting distance of each other, and in touch with one of the two main bodies into which the rebels had divided. At the same time the Katikiro, who considered our columns far too weak, was hurrying up to support us with 500 guns and a host of spearmen.

The Mahommedans were told to surrender their arms or quit the country, otherwise they would be attacked next day. The majority surrendered.

Leaving Arthur at Kibibi to receive the arms, which were now being brought in, Owen and I led the remainder of the force, now strengthened by the Katikiro, against the second body of rebels in the heart of Butunzi. They did not, however, await our arrival. The lesser people dispersed, and sought refuge with their Christian kinsfolk, while about 600 irreconcilables withdrew to Koki. They could not be allowed to rest there, so Lieutenant Villiers, who had joined me, was sent with a small force to dislodge them. This he succeeded in doing without fighting, and the last band of the enemy disappeared.

Thus ended the Mahommedan attempt to place Uganda under the Mussulman flag. In the first war the natives had fought well, but their efforts often lacked system and direction. In the second war the enemy was beaten in the field, but as the nature of the season and other reasons prevented an energetic pursuit, the rebels regained their cohesion and strength. In the third war they were beaten in detail to start with, and then given no rest as long as an armed body held together. This is allowed to be a sound maxim in fighting savages. A mere victory counts for little, they will re-assemble and try again. But if the victory be followed up at once, and the enemy be defeated every time he tries to re-assemble, and driven from pillar to post, he soon loses heart and gives in. The main thing is to take the initiative and keep it.

LECTURE III.

UNYORO EXPEDITION, 1893–94.

This lecture is to deal with the Unyoro Expedition of 1893–94, with special reference to a few points relating to bush fighting, and to the engineering work that was done. Unyoro is a large Bantu kingdom, which lies north and north-west of Uganda, on the plateau that occupies the area embraced between the Equatorial Lakes and the Victoria Nile. In point of area it is considerably larger than Uganda, although it was formerly tributary to the latter country. It is divided into 13 provinces proper, but Kabarega, its king, had extended his sway to the west of Lake Albert, and, southward, had overrun and occupied Toru, Usongora, and Kitakwenda. He had also great influence with the Wakedi, a Nubian tribe dwelling east of the Victoria Nile, who furnished some very good fighting material for his army. The Shuli, another Nubian tribe, who lived on the right bank of the Nile proper, south of Wadelai, were also more or less dominated by this energetic potentate. The gradual deterioration that had taken place in Uganda after the death of Mtesa, and during the protracted civil troubles, had afforded Kabarega an opportunity of extending his influence, an opportunity of which he had taken full advantage. He was undoubtedly a capable man in some ways, and had fostered trade with the Arabs of the East Coast, but practically turned this trade into a monopoly, for he, and he alone, was the middleman. He had abundance of ivory in his kingdom, and this he bartered for guns and ammunition, the ordinary rate being 35lbs. of ivory for a musket, or thereabouts. As he was careful not to allow the Arab traders to pass beyond his kingdom, the trade in arms north of Unyoro lay entirely in his own hands, and from the Nubians of the north he could get three tusks of ivory for a musket. On these terms he throve, amassed considerable wealth, and formed and armed a formidable standing army of over 3,000 guns. This standing army was quite distinct from forces he could raise on the feudal system, and altogether he could, probably, put in the field about 6,000 guns. Unlike the kings of Uganda, who disseminated their askari over the provinces, Kabarega retained his standing force of *Balasura* concentrated in the districts surrounding his capital, and thus under his immediate control and supervision. Of course, like Uganda, Unyoro could put in the field many thousands of spearmen.

In 1862 Unyoro was first visited by Europeans in the persons of the famous explorers Speke and Grant, who had travelled there from the East Coast of Africa. Two years later Samuel Baker reached Unyoro by way of the Nile. At this time Kamarasi was king of the country, and had his capital at Mruli. So far the Europeans were only friendly visitors.

In 1872 Baker again entered Unyoro, but now he was the accredited agent of the Egyptian Government, in whose name he was annexing the countries of the Upper Nile. He found Unyoro much changed in the last eight years. On Kamarasi's death there had been civil war, and Kabarega had ultimately secured the throne, but a rival, Rionga, was still in existence in the north of the country near Mpino. Forming a post in the latter's country, Baker marched to Kabarega's headquarters, which had been shifted to Masindi. Kabarega was at first very friendly, and volunteered to place his kingdom under the protection of Egypt. But this was only to gain time. He made one deliberate attempt to poison Baker's followers by a gift of poisoned beer, and nearly succeeded in his dastardly design. Open hostilities then broke out, and Baker found it necessary to retreat on Mpino, which he reached after suffering severe loss. The Wanyoro delighted in ambuscades. They generally stood on the banks of a swampy stream, where on Baker's side they had posted a body of men in the long cane grass in a clearing parallel to, but invisible from, the road. When Baker's column closed up to force the passage of the stream, a shower of javelins was rained on him from the cleverly concealed ambuscade. The discomfiture of Baker undoubtedly raised Kabarega's prestige.

In 1877 Gordon founded some stations in the north of Unyoro, and sent Emin Pasha to open relations with Kabarega, and later in the same year Casati was deputed by Emin as resident at Kabarega's capital, now at Nyamoga. At first, as before, Kabarega was full of friendship, but when he saw his opportunity he seized Casati and his men and sentenced them to death. Casati, however, escaped, and made his way with extreme difficulty through the jungles to the eastern shore of Lake Albert. Here he was concealed for some time, until he was picked up, nearly starved, by one of Emin's steamers. Emin, in revenge for this insult, shelled the coast town of Kibero, but as no reprisals were made against Kabarega himself, and no punitive expedition was sent into his country, Kabarega again posed in native estimation as victorious over the white men. His reputation was further increased by the final abandonment, a few years later, of the few Egyptian stations that had been made in the northern part of his kingdom. His only rival, in public opinion, was the great Mtesa, King of Uganda, who, however, died in 1884, and was succeeded by the weak and incapable Mwanga. For the next six years little is heard of Kabarega, but in the end of 1889, when the Mahommedans were expelled from Uganda by the combined forces of the Christians, we find Kabarega harbouring and assisting these exiles. Indeed, when in 1891 Lugard led his expedition against the Mahommedans, Kabarega supported the latter with 1,300 guns.

Later in the same year Lugard went to Kavalli's, and had two fights with Kabarega's warriors on his northward march from Lake Albert Edward, not to mention some skirmishing. Having secured Selim Bey's Soudanese, he established most of these in a line of five forts, running north and south, to protect Toru, Usongora and Kitakwenda, from Unyoro aggressors. Later the forts were wheeled round, and thus directly deprived Kabarega of the province of Chaka, while the license of these uncontrolled Soudanese wasted the two additional provinces of Mwengi and Buyaga up to the Msisi River. Kabarega thus practically lost six out of his 16 provinces, and had the Soudanese behaved well towards the natives, no doubt the Wanyoro and other inhabitants of these provinces would have welcomed the advent of European authority. But the Soudanese behaved very badly, and alienated the native population.

When Lugard first came to Uganda, Kabarega had made overtures of friendship, overtures that had been at once rejected. Then had followed acts of hostility, and finally Kabarega's kingdom had been curtailed by an objectionable line of forts. Kabarega was now the implacable enemy of the British, and, though all his attacks on the forts themselves were repulsed, he caused the garrison some loss by harassing their foraging parties.

In the summer of 1892 Williams had tried to make peace with Unyoro, but Kabarega had declined his terms, and intermittent hostilities had continued in southern Unyoro.

Such was the state of affairs when Sir Gerald Portal took over the administration in 1893. One of the first steps he took was to put a stop to the indiscriminate raiding which was the constant practice amongst the Soudanese garrisons of South Unyoro. But the cessation of raiding, coupled with the reduction of the garrisons, was misunderstood by Kabarega. He again attacked the forts, and, though beaten off, he scored one success by surprising and defeating a small party under Shukri Effendi.

So far I have glanced briefly at the previous history of the relations between Unyoro and the Europeans who from time to time came into contact with that country. Before describing the Unyoro Expedition of 1893–94, which shattered Kabarega's kingdom, I must touch on certain preliminary arrangements that took place before the arrival of Colonel (now Sir Henry) Colvile, thanks to which, as he has himself officially recognized, his operations against Kabarega were rendered feasible.

These preliminary arrangements involve the consideration of a far-reaching principle of warfare against savages, which should be especially interesting to us as Engineers, as it has to deal with the proper application of defensive works. It is generally admitted that in operations against semi-civilized or savage peoples a defensive attitude is out of place. Even against vastly superior numbers the greatest chance of success lies in a vigorous offensive. But forts and defensible posts are from their nature purely defensive, and hence it may not be out of place to consider how far they are necessary or desirable. It stands to reason that if our whole force is split up into small detachments, each locked up in a fort, our offensive power is practically *nil*, if the forts are out of supporting distance of each other, and the enemy is still in any sort of organized strength. On the other hand, to retain our whole force as an active body for offensive operations in the field is impossible. We may start in this way, it is true, but as men are wounded or fall sick, and our transport is reduced, as sooner or later it must be, we find ourselves burdened with an ever-increasing train of non-combatants, until ultimately the power of movement, without which the offensive is impossible, is denied us. One of these arguments shows the evils of over-fortification, the other the necessity for some fortification.

The troops in occupation of an enemy's country want some sort of a base, some depôt or place in which surplus stores can be placed, and in which sick and wounded can be securely left. As the force moves forward advance posts may become necessary, but we must ever bear in mind that every additional post means a proportion of our fighting force detached for its defence, and to this extent numerically reduces our fighting column. I have said numerically because the actual fighting efficiency of the moveable column may be greatly increased in spite of these very detachments. Thus it would appear a golden rule in such military operations to construct the minimum number of defensible posts that is consistent with the freedom of movement of our fighting column. It is easy to enunciate this rule, but, as many of my brother officers will bear me out in saying, it is often difficult in practice to say exactly what is the minimum required.

Of course, we can find cases in which an expedition has committed itself to military operations without a line of communications. The very expedition I am about to describe started in this way. But if prolonged operations become necessary, then fortified depôts or centres become obligatory. After the enemy's organized armies have been defeated and dispersed, it may be desirable, as in Burma, to largely multiply our fortified posts, but this is not a contradiction of the general principles I have enunciated. By the break-up of the enemy's force it follows that smaller columns are capable of coping with any desultory bands that may still hold together, and to facilitate the offensive movements of these smaller columns each is given a fortified centre, from which it acts with the knowledge that its stores and sick are in perfect security.

You may wonder what this has to do with the Unyoro campaign, so I will now give you, as an object lesson, the preliminary arrangements which I have already mentioned.

When Sir Gerald Portal took over Uganda and organized our strength in that country, he abandoned one of the Company's forts and built two new ones, with the net result that we had about 650 men distributed over a length of nearly 400 miles, and holding nine fortified forts, most of which were absolutely out of supporting distance of each other, and four of which were practically in hostile territory. We may omit the garrisons in Kavirondo and Usoga, as these could not have been reduced, and the former was merely nominal. This would leave us with 600 men distributed in seven forts: 350 men and three forts in Uganda, and 250 men and four forts in Unyoro. Before the outbreak of the last Mahommedan war I had already abandoned one of the Uganda forts, that at Kibibi, as a manifest source of weakness, and had thus got 350 men in two forts about 21 miles apart. The practical lesson of this war showed that out of over 600 soldiers we could only, after seriously weakening our garrisons, count on about 200 men, or, say, one-third of our strength, for active operations in the field; the rest were locked up in the forts looking after stores, the wives and families of the combatants, and the sick. If we consider the cases of Uganda and Unyoro separately, the contrast is even more striking. In Uganda we could turn out 140 men out of 350, or about 40 per cent.; while in Unyoro, the forts being in hostile territory, Owen could only detach 60 men out of 250, or about 24 per cent. There was something evidently very defective about an organization that could do no more than this. The fact was, most of our troops were locked up in little forts and reduced to a purely defensive attitude.

Now in dealing with savage kings in the heart of Africa we must remember that British prestige has a totally different meaning from that we are accustomed to. The British Empire may be the greatest in the world, our fleets may dominate every sea, and we may have armies capable of eating up all these savage kings combined, but whatever may be our strength elsewhere, if we can only put 200 soldiers in the field against him, the savage king will judge of our power by what he sees. Thus it behoved us to make the most of our little force, and show that we were capable of striking hard blows if it should be necessary.

It was evident that we could not stand still in Uganda, and that in the near future we should have to face a serious conflict with Unyoro. Indeed, there were many indications that the surrounding peoples were watching with interest the development of the struggle between Uganda the friend and Unyoro the enemy of European progress. Thus a forecast of our future military requirements pointed to the advantage of a concentration of our little force, as only by reducing the strength of our garrisons could we increase our offensive strength. A concentration in Uganda was clearly the best, as in that friendly and productive country the security and feeding of our garrisons was more assured.

Not only did military considerations point to this course, but by a concentration in Uganda we could greatly cheapen the cost of administration.* South Unyoro had proved a very doubtful bargain. Thanks to the oppression of the natives by the Soudanese garrisons in the past, the inhabitants of the protected districts had for the most part become lukewarm friends or bitter enemies.

In addition to these reasons, I may mention that Sir Gerald

* The cost of the temporary protectorate while I was in charge came to about £27,000 per annum; under my successors its cost has about doubled.

Portal, my immediate superior, had written to me after the Mahommedan outbreak emphasizing his views that Toru and Southern Unyoro should be abandoned without delay. The letter was, of course, so diplomatically worded that the sole responsibility for the evacuation or retention of our position in South Unyoro rested on my shoulders.

I accepted this responsibility, and as every dictate of common sense and military expediency pointed to a concentration of our strengh in Uganda, a concentration that would enable us to put in the field such a formidable force as would make our power a thing to be feared beyond the limited zones of scattered forts, I decided to temporarily abandon the Unyoro forts and concentrate in Uganda.

Of course, I decided on this step with my eyes open to the probability of a sentimental outcry in certain quarters about the retrocession of our flag, etc., etc., but one must be prepared for little unpleasantnesses of that sort in the execution of duty, and fortunately our duty in this case was perfectly clear.

At the same time, I did not want to break faith with the few friends we had in the so-called protected provinces, and so obtained from Mwanga, king of Uganda, sufficient territory to enable me to transfer our friends to the security of Uganda, where they would enjoy all the privileges of protection. Major Owen made careful investigations as to the numbers we should have to provide for, and found that while Kitakwenda was bitterly hostile to us, Usongora would welcome our departure, and that the total strength of our friends amounted to 2,000 Wanyoro settled at our forts, and 5,000 followers of Kasagama of Toru. But the latter declined to emigrate to Uganda, and asked instead that we should let him have 200 extra muskets and a supply of ammunition and hand over intact the fort which was located in his territory; he considered that if this were done he could hold his own. His request was granted, and he was assured that within six months we should send him additional supplies and should support him if Kabarega attacked him.

The 2,000 friendly Wanyoro, friendly to us because they were enemies of Kabarega, and 4,500 Soudanese, were withdrawn into Uganda and moved to their allotted places without difficulty. And so well did Owen, Villiers, Grant, Wilson and others carry out their separate duties that not a single complaint of ill-usage or looting was made by any of the inhabitants of the districts traversed.

This step taken, we devoted our energies to improving our fighting machine as rapidly as possible. I found that, thanks to the concentration and other economies, I could afford to spend more out of my limited funds on the military items. The troops benefited in various ways, as we re-cast the rates at which their pay, etc., was issued, and a reserve force of 300 men was enlisted.

Each reservist was put through two months' preliminary drill, and was then given half the pay of a regular soldier and rations. In return for this he was liable for garrison duty in time of war and had to put in a specified number of drills per month to maintain his efficiency.

This worked well, and in a short time I could put in the field a moveable column, capable of offensive operations, of 500 drilled soldiers, while at the same time garrisoning Uganda more strongly than it had been in the past. This was accomplished with an increased military expenditure of only 25 per cent. over the former system, under which we could only place in the field 200 men. And the total annual expenditure of the administration was not exceeded.

Usoga, which had periodically given trouble in the past, was allotted a small garrison, but the bulk of our men were kept in Uganda itself, in two groups of forts. One group of two forts within supporting distance of each other was located on the N.W. salient of Uganda, within five days' march of Kabarega's capital, and absorbed about 150 men, while the remainder were located in three forts in the heart of Uganda, within supporting distance of each other and strategically grouped round the probable focus of any internal disturbance. I may mention that groups of forts were used simply to facilitate the feeding of these large bodies of Soudanese without undue hardship on the inhabitants of the country, for you must understand that a company of Soudanese soldiers, with their wives, families and followers, in number approximated to the strength of an English battalion at home.

The concentration had another important effect, which my sentimental critics might well set off against the intercession of the flag, etc.: it resulted in the liberation of some 2,000 slaves, and the conversion of their former masters into an anti-slavery party. This is really a digression, but perhaps you may be interested in hearing the details. I mentioned in a former lecture that our Soudanese soldiery had a large number of Lendu slaves, about 2,000 in all. My predecessor had left the status of these people alone, as it was considered that the time was not yet ripe for their emancipation, and the movement would, it was felt, be resented by the Soudanese soldiery, the masters. Once we got all the Soudanese under a central authority in Uganda, I saw my way to tackling this question, but I wished to do so in such a way as not to cause unnecessary friction. So I issued a notification that every Soudanese who possessed slaves was responsible for feeding and clothing them properly, especially for feeding them. This notification was hailed with every sign of satisfaction on the part of the masters, as it appeared to put the seal of official sanction on the institution of domestic slavery, which they had feared we would abolish. But they took a different view of matters when they saw the logical sequence of the pleasing notification. Every time a Lendu was caught stealing food, a somewhat frequent occurrence, his Soudanese master was had up, and, as it was generally abundantly clear that the Lendu in question was improperly fed, the master received on his own person the specified number of lashes that was customary on conviction of petty theft. The procedure was perfectly logical, and freely recognized as such. We did not interfere with the soldiers' property, but, on the other hand, held him responsible for the action of his slave. After a fortnight of this sort of thing the masters came forward and prayed me to liberate the Lendus, and make them responsible for their own actions. After a little hesitation on my part, which made the masters more zealous exponents of the philanthropy of emancipation, I graciously bowed to public opinion, and declared 2,000 Lendus free and independent citizens. Their thieving propensities were quickly curbed, and, enlisted on fixed and regular wages, they furnished an excellent and economical transport corps that did good work in the Unyoro campaign.

It was now becoming evident from many signs that the winter of 1893 would probably see us engaged in hostilities against Unyoro. Kabarega, who had at first viewed with alarm the proximity to his capital of our new frontier forts, began to again make himself felt. He collected a force to watch our forts, and to cut off supplies, even going the length of ostentatiously posting a line of picquets along the frontier, who did not scruple to interfere with the Waganda.

But, warned by the hardships Lugard had encountered on his Mahommedan campaign, which took place in an unfavourable season, I decided to postpone any active operations until December, when the rains would be nearly over, and the crops would be ripe. Then I intended, should Kabarega have not made peace, to direct Owen, with 250 Soudanese, one Maxim, and a Waganda contingent, against Kabarega's capital, while Arthur, with 150 Soudanese, one Maxim, and a second Waganda column, invaded the east of Unyoro *viâ* Mruli, and cut off Kabarega's favourite retreat into the Wakedi country across the Nile.

But at the eleventh hour Colonel Colvile, of the Grenadier Guards, arrived to take command in Uganda, and reaped the benefit of our preparations and our plans. He fully agreed with all that had been done, and asked me to remain as his chief staff officer for the approaching campaign. In one respect the original plans were modified; the simultaneous attack against Mruli was abandoned, as Colonel Colvile wished to extend our main operations further than had originally been intended, and it was felt that the execution of these extended operations would necessitate the concentration of our whole strength on the main attack.

Kabarega had meanwhile made it abundantly clear that we need not expect peace proposals from him. He had not only insulted our frontier posts, but had sent one army against our friend Kasagama of Toru, and another to invade the south of Toru. Colonel Colvile accordingly declared war against Unyoro, and ordered Owen to invade the hostile province of Bugangezi in order to draw off the attack on Toru, while our main expedition was being organized.

This mission Owen carried out with his customary promptitude. In seven days he had marched 110 miles, and collected his force of 2 Europeans, 200 Soudanese, 100 armed porters, and 1 Maxim near the frontier. Then by a long and trying night march through a succession of swamps, many of them over waist deep, he got his force within three miles of the enemy's headquarters by dawn. The enemy was in considerable strength, mustering some 2,000 guns, but during the day Owen drove them from one position to another, captured and burned their headquarters, and by next morning found himself undisputed master of the greater portion of the province. After collecting a lot of food, he retired again to our frontier forts, confident that the news of his victory would draw off the hostile force that was invading Toru. We afterwards found that it was so. Some days later a second fight took place, in which Captain Feraj Effendi and 70 Soudanese defeated a large force of the enemy, after an engagement lasting nearly two hours.

While Owen was keeping the enemy occupied on the frontier, the expeditionary force was rapidly organized into two divisions or bodies. The headquarter column, under the immediate command of

Colonel Colvile, was to consist of two portions, the Government troops and transport, and a Waganda contingent, under the chief of Bulamwezi, for scouting and foraging purposes. The Government force consisted roughly of eight Europeans, 450 Soudanese, with two Maxims, and about 450 porters, of whom over half were armed; the Waganda contingent of 400 guns, with about 1,200 spearmen; the total strength being about 2,500 men.

The other division consisted entirely of Waganda, under the leadership of Kakanguru, and mustered 12,000 men, with about 3,000 guns.

It was arranged that this force should concentrate on the frontier towards Ntuti, moving to that point in small columns by separate roads, under cover of our frontier forts.

On the 13th December, 1893, the headquarter column marched from Kampala. Amongst our impedimenta was the steel boat carried in sections, and a quantity of trade goods, with which to purchase food if any of the Wanyoro districts surrendered. In five marches we reached Fort Raymond, where we halted for a day. These preliminary marches were far from pleasant, as it rained hard nearly every day, and some of the swamps were difficult. At Fort Raymond we obtained more definite news about the crossings of the Kafu River, which led Colonel Colvile to order the concentration to take place on Ntuti, with a view to a direct advance on Kabarega's capital. An alternative route was suggested more to the west, but, as it proved, we were fortunate in not choosing it, or we should have encountered those additional swampy rivers that deterred Lugard from his contemplated invasion of Unyoro after his successful battle at the Kayangora.

On the 19th December we left Fort Raymond, and on the 25th of the same month reached Ntuti. The route taken avoided most of the swamps that Lugard had encountered, and we seemed to be finally quit of the rains. The whole concentration had worked very smoothly. The Catholic contingent from Buddu, which had the longest distance to march, was encamped near us, while Kakanguru, with the bulk of the Waganda army, was one day's march ahead at Kaduma, a fertile district in the enemy's country. Next day the whole army assembled at Kaduma.

This preliminary march of nearly 130 miles had done everyone a lot of good. At first the Europeans had been a very sickly lot. Colonel Colvile and Dr. Moffatt could hardly walk, Arthur and Villiers had suffered from fever, and Purkiss was hardly strong again after a bad attack of hæmaturic fever. But on reaching Kaduma all were well, and eager for the great fight that was expected at the Kafu.

On the 27th December Colonel Colvile ordered a halt to allow the various contingents to fall into their proper places. This gave us an opportunity of repairing the lock of one of the Maxims, which had got out of order owing to the striker pin getting bent and broken. With the help of an Mganda artisan I got a new striker brazed on and the gun was serviceable. It was generally spoken of as the dummy, but the said dummy was the only Maxim that came into action during the expedition, and it did its work well.

Starting from Kaduma on the 28th December, we reached the south bank of the Kafu in two marches, and found it as formidable an obstacle as had been anticipated, in fact, more so. Our guides had made a mistake the last day and brought us to Usamba instead of to Baranwa, where the river was only about 400 yards wide.

At Usamba, on the other hand, it was nearly 1,000 yards wide, and proved about seven feet deep. The whole bed was overgrown with papyrus, and both banks were wooded, though our bank had a slight command. It did not look an inviting place to force a passage. We hoped to be able to throw some men across in the steel boat, but although there was a tortuous open channel which canoes could use, the boat could not get through. The only advantage of Usamba was that food was plentiful.

Next day the force halted while Colonel Colvile made the following dispositions:—Major Owen, with a company of Soudanese, was sent up the river to search for the Baranwa crossing, while Captain Thruston was sent down stream to see if he could find a good passage, and, in any case, to divert the enemy's attention. I was detailed to superintend the construction of bridges or causeways across the river about two miles above Usamba, the Waganda furnishing a working party of about 7,000 men.

By the same afternoon we had progressed sufficiently to allow of men wading to the opposite bank, so Colonel Colvile sent Arthur with a company of Soudanese and 1,000 Waganda guns to cover the bridging operations by establishing himself on the enemy's bank. Strange to say, the enemy did not oppose us. Captain Thruston had found the enemy watching a passage lower down, and Major Owen had exchanged shots with a hostile party which guarded the Baranwa crossing, but Arthur got over unopposed and secured our bridging operations from molestation.

By one p.m. on the 31st December, 1893, two out of the three causeways were practically complete, and the third was passable, so at two p.m. Colonel Colvile gave orders for the main body to cross. This was a somewhat tedious operation, and it was not until after sunset that the whole force was encamped on the enemy's side. Next day we advanced, watched by small bodies of the enemy from the summits of the surrounding hills, and on the 2nd January, 1894, obtained possession of the enemy's capital without opposition.

So far the expedition had only experienced the mildest of mild skirmishing, and we could hardly account for the timidity displayed by the enemy, who in the two small fights on the frontier had shown unexpected pluck. The facts of the case appear to have been as follows :—Kabarega had become over-confident, and divided his force into four detachments: one had been sent against Toru, and a second to invade Usoga, while the third was masking our frontier posts. Thus Kabarega had only one-quarter of his army at his immediate disposal. On our declaring war, he at once sent runners to recall the Toru and Usoga armies. In Lugard's campaign against the Mahommedans it had taken his army a month to reach the frontier, and Kabarega had not anticipated that our movements would be so rapid that in 21 days we should not only be across the frontier, but in occupation of his capital. The Toru and Usoga armies had not been able to re-join him in time, the force told off to guard the frontier were very dispirited after the rough treatment they had received at Owen's hands, and Kabarega did not consider himself strong enough with only one-quarter of his army to dispute the passage of the Kafu or defend his capital. He apparently considered that by making attacks on Toru and Usoga he would keep us fully occupied in defending those distant districts, and had overlooked the fact that we could equally well relieve the pressure on those countries by making a direct counter-attack on his capital.

Kabarega and his force had retired to the eastward, and from prisoners we learned that the Toru army had at length succeeded in rejoining him, but were hardly yet in fighting trim, as they had lost heavily in actual fighting, and even more severely in their forced marches back from Toru. There was nothing for us to do but try to bring Kabarega to an action, so Colonel Colvile moved our whole force in pursuit. The enemy kept hovering round in small parties, and our foragers suffered some loss. On the 4th January the Waganda scouts reported Kabarega's army in force a few miles ahead of us at the entrance to some difficult forest country, so Owen was sent out with a company to reconnoitre the enemy's position. He found, however, that he had only a rear-guard in front of him.

Colonel Colvile, concluding that the enemy were trying to delay us by well conceived rear-guard tactics, sent me ahead next day with a strong advance guard of about 1,000 Waganda and half a company of Soudanese, with orders to deal vigorously with any rear guard that might threaten to delay the advance of the main column. Colonel Colvile had rightly foreseen the enemy's tactics, for after advancing about 10 miles my advanced party reported the enemy strongly posted in some dense bush at the entrance to a small defile, which was commanded a little further on by a steep and, in places, precipitous hill within musket shot of the road. It was not, strictly speaking, the defence of a defile, as the enemy's main position was in advance of the actual defile. I ordered the Waganda to make an immediate attack, and followed in support with the Soudanese. Then arose a fusilade that in volume was very creditable to the comparatively small numbers engaged. It was only by the firing one could judge how the fighting was going, for in the bush one could see but little. When I came up with the Soudanese I found that the Waganda had driven in the enemy, but had been more or less checked in their pursuit by the fire from the rocky hill I have already mentioned, which commanded the pass. Against this hill I led the Soudanese, brushing before us some of the enemy who were lurking in the bush, and drove the enemy off the hill. Once in possession of this, the pass was ours. In this trifling skirmish a quantity of powder had been expended, but though a good deal of the firing was at close quarters, the losses were small on both sides. The small losses were largely due to the density of the undergrowth. When our main body came on we again advanced, and pitched camp a few miles ahead. As the Waganda had succeeded in losing touch with the enemy, Owen and I were sent out to reconnoitre, and from the summit of a neighbouring hill we could make out a large camp of the enemy. That night we were nearly burned out of our encampment by a forest fire, which I have a shrewd suspicion was caused by the enemy, for on retiring from the defile the day before they endeavoured to check pursuit by firing the jungle, and used similar tactics on other occasions.

On the 6th January we advanced in battle formation against the enemy, who were still in force about 6½ miles away in the Budongo forest. The Soudanese and Maxims occupied the centre, and on either flank stretched a line of parallel Waganda columns, while the whole force was covered by a line of skirmishers. The country was very difficult, and our advance was necessarily slow. At one period we found a ridge which lay across our path occupied by the enemy, but these fell back before our skirmishers, and we reached the hills of Bitiberi, 2,500 yards from Kabarega's camp, about an hour before dusk without fighting.

Colonel Colvile decided to attack the enemy next morning, but next morning his camp was empty, while columns of smoke about eight miles away in the foodless forest marked his new position. The enemy had declined battle.

Colonel Colvile had now to decide what should be done. We knew that the enemy had concealed grain stores in the forest, while if we followed him we must go on short rations. To follow him would be to play his game, for he could always retire faster than we could advance deployed. Colonel Colvile accordingly decided to abandon further pursuit and retire two days' march to the eastward, in hopes that Kabarega might be tempted into the more open country. Accordingly we moved to Kibona, a fertile district near the former capital of Unyoro—Masindi. From this point scouting parties were sent 15 to 20 miles more to the eastward towards Msuli.

This stratagem succeeded, for we soon heard from deserters that Kabarega had left the forest and was returning to his capital, chuckling over the artful way in which he had played with the Europeans. Colonel Colvile decided to cut him off, if possible, so a flying column was at once organized under the command of Major Owen. This column consisted of four Europeans, 300 Soudanese, with a Maxim and 800 Waganda guns, and started before daybreak, while the remainder of the camp stood fast. At first all promised well, and Owen had accomplished more than half his journey undiscovered. Then some irresponsible Waganda spoiled his plans by pushing ahead and stumbling on one of Kabarega's detached parties. A skirmish followed, and Owen supported the Waganda and drove back the Wanyoro, but Kabarega got sufficient warning to escape once more to the forest.

It was now abundantly evident that the enemy could not be induced to hazard a serious engagement, so Colonel Colvile decided on new tactics. Knowing that the enemy's food supplies in the forest could not be inexhaustible, he determined to blockade Kabarega's army in the forest of which they were so fond. The headquarter division was ordered to occupy Kitanwa, while Kakanguru's division was located at Kisibagwa; this arrangement cut off from Kabarega the food-supplying districts south of the Budongo Forest, and we had during our recent operations towards Kibona pretty well exhausted the food thereabouts. Thus Kabarega must either come out and fight us or draw food from the extreme north, a contingency which was provided for later.

All this time our foragers had daily skirmishes with the enemy, and both sides were losing men.

On the 17th January the headquarter column reached the fertile district of Kitanwa, while the same day Kakanguru took up his position at Kisibagwa. During the march a brisk skirmish had taken place on our right, in which the enemy had been driven back. On arrival at Kitanwa I was sent out with half a company to reconnoitre the road to Kibero. Dispersing a few small bodies of the enemy *en route*, I reached the edge of the plateau an hour before sunset, and looked down on the Albert Nyanza and the flourishing town of Kibero, a thousand feet below me. That same night Kibero was occupied.

Colonel Colvile had decided to retain his hold of this direct route from Uganda to Lake Albert, and place the steel boat on the waters of the lake. To this end we had proposed to build three forts, one at Kibero, another near Kabarega's capital, and a third to command the passage of the Kafu River. But on arrival at Kibero we found there was no cultivation on the arid shores of the lake, so a fourth fort became necessary in the fertile district of Kitanwa.

On the 18th January a site was chosen for the Kitanwa Fort, and Villiers was told off to build it. The same day the steel boat was put together and launched on Lake Albert. Arthur had meanwhile reconnoitred south, and seen a number of canoes, which Colonel Colvile wished to capture. Accordingly Arthur and Purkiss were sent off in the steel boat with as many men as it could hold. He came on the enemy encamped in a little bay, which was completely commanded from the cliffs. Under a heavy fire Arthur forced his way in, landed, and drove back the enemy with his Soudanese, while Purkiss and his sailors secured the enemy's canoes. The whole affair was admirably managed.

On the 20th January Major Owen, with a column of about 300 men, was detached with orders to march to Magungu, in the food district north of the Budongo Forest, and also to ascertain the state of affairs at Wadelai. To facilitate his operations he was given the steel boat under Purkiss, who had orders to keep parallel to his advance.

Meanwhile the headquarters remained at Kibero, and commenced work on the small fort which was intended to protect the valuable salt works of Kibero and the small harbour in which our boat was to lie.

Kibero was a far from prepossessing spot, but its salt works were well worth seeing. The soil was impregnated with salt, and the native method of extraction was as follows. Small level spaces were made, and flooded with water to the depth of a few inches. This dissolved out the surface salt, and on evaporating left a white deposit. The impure deposit was scraped up and placed in large earthenware pots, into which water was daily poured. A small hole in the vessel allowed the brine to escape, and this was collected in smaller pots, and evaporated until a solid block of excellent salt was obtained. Another feature of Kibero was its boiling sulphur springs. Perhaps I may be wrong in saying sulphur, for our doctor discovered that these springs possessed other valuable medicinal properties. The fort-making was very distasteful to our men, and our sick list had rapidly increased to an alarming extent since work was commenced in earnest. Dr. Moffat was called in from Kitanwa, and advised us to give every patient, if his malady was not apparent, a large tumbler of Kibero water every morning at sick parade. This treatment worked wonders, and our sick list dwindled in two days from nearly 50 to about 3 per cent. Work on fort building was felt to be preferable to the repetition of a dose of the potent waters of Kibero.

For 10 days we were diligently employed on fort building, and Kabarega was beginning to feel the effect of Col. Colvile's new plan. Having nearly exhausted his magazines of food in the forest, he had shifted his force towards its outskirts and sent out foraging parties, which were invariably driven in again with loss. On one occasion he made a partial night attack on Kibero, but Villiers was equal to the occasion, and drove off the enemy with a loss to his garrison of only three men. A day or two before two Waganda foraging parties had, by mistake, fired on each other, and killed or wounded several men before the mistake was discovered.

Things now began to become rather more exciting. Both Villiers and Kakanguru reported that Kabarega was advancing with the apparent intention of attacking Kitanwa, and thus separating the headquarters from the Waganda division at Kisibagwa. Colonel Colvile accordingly ordered Kakanguru to attack Kabarega in flank on his exit from the forest, rightly considering that, as the fort at Kitanwa was now nearly completed, Villiers could deal with any attack on that place. Before we heard the result of these orders we had further excitement.

On the 31st January the steel boat returned with some wounded men, both Purkiss and his crew being well-nigh exhausted from hardships and starvation. He reported that Owen had one encounter with the enemy on the 23rd January, but that after that date he had disappeared, and lost touch with the boat. Purkiss had attempted to enter the Victoria Nile and make for Magungu, but the mouth of the Nile was choked with sudd and vegetation, and after attempting a passage for several days the boat could not find an open channel. Purkiss had then gone down the Nile proper for about 15 miles to Iyar's, thinking that Owen might be on his way to Wadelai. The inhabitants had at first proved friendly, but suddenly made a treacherous attack on Purkiss's small party, and, but for the gallantry of one of his Soudanese privates, would have captured the boat. As it was, Purkiss escaped with difficulty. Since then he had been unable to get food, as his crew were too small to effect a landing.

This was serious news, so Colvile ordered me to select a new crew and start next day to try and discover what had happened to Owen, and in any case to push on to Wadelai and ascertain the state of affairs there. The same night, however, news arrived from Owen that he was returning to Kibero, and he marched in next day. It turned out that his force had a second fight with the enemy on the 26th January, which resulted in a second victory, and cleared Magungu of the enemy's foraging parties. In the absence of the steel boat he had, however, been unable to cross the Nile, and so returned to Kibero.

As Colonel Colvile was most anxious to find out what was happening at Wadelai, he sent Owen off in the steel boat with a strong crew, and as the forts at Kibero and Kitanwa were now ready, marched to Hoima, where the headquarters of the new Unyoro command were to be situated. In addition to building these two forts, we had provisioned them for four months.

We now heard of the complete success of the movement Colonel Colvile had ordered against Kabarega. Kakanguru had advanced on the 28th January, and on the 31st found Kabarega's army located in three camps, near the edge of the forest. Kakanguru feinted against the flanks and advanced to attack the centre. But as Kabarega simultaneously moved forward in ignorance of the proximity of the Waganda, the actual meeting was rather a surprise for both sides. The result was a complete victory for the Waganda, who not only routed the enemy, but succeeded in capturing some ivory, powder and guns, and 60 head of cattle and 3,000 goats and sheep.

On the 10th February work was commenced on Fort Hoima, and Arthur was sent off with a small column to bring fresh stores from our frontier forts in Uganda. Marching rapidly, he carried out this task successfully, and without encountering much resistance.

On the 12th February Major Owen turned up at Hoima. He had reached Wadelai after a very adventurous journey, and had succeeded in making a treaty of peace with the chief of that place. Wadelai is about 30 miles from Lake Albert on the right bank of the Nile. Half the distance was accomplished by night, but when day dawned the inhabitants turned out and opened an ever increasing fire on the steel boat. Owen, however, pushed stubbornly on without firing a shot in reply till he got into touch with Wadelai. A parley then took place, and peace was made to the satisfaction of both parties.

As Kabarega's power was now broken for the time being, Colonel Colvile decided to send Owen and Villiers to Toru to organize a confederacy of Toru, Mwengi and Chaka, the chiefs of which were all well disposed. On the 18th February this small column started through unknown country. I may at once say that Owen's mission was successful.

As Fort Hoima was now defensible, Captain Thruston (since Major) was left in command with two companies of Soudanese, and the headquarters moved to the Baranwa crossing of the Kafu River on the 21st February. Though the enemy's organized resistance was now at an end, we suffered from small bands, which, though always driven off, sometimes caused us a little loss. For instance, during the march to Baranwa we lost six killed and wounded, mostly stragglers.

Colonel Colvile now permitted the Waganda under Kakanguru to return to Uganda. The expedition had lasted longer than usual, and as the Waganda had suffered severely from small-pox, they were glad to get back. But before letting them go I was sent to go over the list of captives and liberate any Wanyoro that might be prisoners. This was a far from easy job, as nearly 1,700 captives had to be examined. 1,175 proved to be Wanyoro, and were allowed to return to their homes; the remaining 507 were Waganda, who had been carried off into slavery in Unyoro, and who were now set free and permitted to return to Uganda.

In five days the small fort at the Kafu was completed and stocked with rations for six weeks. At the same time a bridge or causeway about a quarter of a mile long had been constructed across the Kafu, and another about 150 yards long across a minor swampy stream. This having been done, a garrison of half a company was told off to Fort Kafu, thus bringing the force under Capt. Thruston's command up to 3½ companies of Soudanese.

The headquarters then marched homewards, and re-crossed the Uganda frontier on the 27th February, 1894. Colonel Colvile returned to Kampala *viâ* Fort Grant and Fort Raymond, while I was sent to explore a new route which led through Bulamwezi.

Having given you a brief account of the events leading up to the campaign and to its actual operations, I propose now to refer to a few of the methods and makeshifts which we employed. Some of my readers may be familiar with most of these, but to others they may be instructive.

Perhaps I had better begin with the organization of our transport, which had special reference to simplicity on the march and in camp. In savage warfare in bush country it is often impossible to lay out the camp in a regular fashion, as could be done, say, at Wouldham. In fact, it is often necessary to make little differences in the arrangements day by day to suit the ground. These alterations are apt to cause more or less confusion amongst untrained transport followers, and anything that militates against the force rapidly, and without friction, settling down into its place in camp, is to be avoided as far as possible.

Our porters were divided into sections, each consisting of two askari, who correspond in this case to non-commissioned officers, and about 24 porters, and each of these sections had to carry about 20 loads. This allowed a considerable margin of spare transport, as is desirable. The loads to be carried were all divided off into sections. Thus to each officer was told off a section of porters, and as his own personal loads and camp equipage did not come to anything like the carrying power of his section, he was handed over other stores, which were always carried with his loads on the march, and stored with his loads in camp. Then each Maxim had a section of porters, and two were told off for the steel boat and for the trade goods.

Each section of porters had a distinctive flag in duplicate. One of these was carried with the section on the march, the other went ahead with the advance guard. On arrival at the camping ground, the staff officer, or, in my absence, the officer of the advance guard, laid out the camp by placing one of these distinctive flags to mark the site of each officer's tent, of each Maxim, and of the boat and stores. Thus, as each section of porters arrived in camp it had only to march on the point where its duplicate flag was placed, unpack loads and pitch tents. As the section marched into camp the officers on duty collected the flags carried on the march, and placed them on the rear face of the camping ground on the positions to be occupied by the respective sections of porters. So, by the time the porters had pitched the officers' tents and secured the loads, their places in camp were ready marked out for them, and no confusion resulted. This arrangement worked very simply, and greatly facilitated our rapidly settling down into our places if the camping ground was irregular.

The same system was adopted with regard to the transport of each company of Soudanese, as each of these companies had also a distinctive flag. There may be nothing new in this idea, but I mention it has having proved thoroughly workmanlike in practice.

There is little I need say about the camp itself. It was always placed on the side towards the enemy, with the Waganda in rear, or sometimes on our flanks. The group system of sentries was always used. One of the Soudanese companies was provided with tents, the others hutted themselves.

As there was always a chance of our being attacked in flank on the line of march, the men, both soldiers and porters, were practiced on the following system :—Each section was considered a unit, and had one N.C.O. leading it, and another in rear. In case of an alarm, or if the halt were sounded, the leading N.C.O. at once halted, and his men closed on him without word of command. Once closed, they moved up under orders of the N.C.O. to join their company. When you take into account that the path was generally so narrow that the men marched in single file, and that, thanks to the frequent little curves in the path and the walls of cane or elephant grass on each side, it was impossible to see far in front or in rear, and when you consider that even our small Government force of 900 men took up about $1\frac{3}{4}$ miles of path when opened out, you will see the reason for the above rule. In case of alarm, instead of the greater portion of our column consisting of a crowd of disconnected individuals, rushing forward to join their companies, the column within a few seconds became a chain of concentrated sections, each acting under the orders of its section commander. Then, without confusion, the larger units were re-formed.

Perhaps a few words about our baggage guard may also be interesting. The system laid down in the textbooks is not altogether suitable to bush warfare, for if you keep your guard concentrated at the head and tail of your baggage column, you are not unlikely to find that some of the intermediate sections of your porters have been cut up and their loads looted before your concentrated baggage guard can get near enough to help them. The system we adopted, with success, was as follows:—One-half the baggage guard was detailed to march with the porters, one section of fours at least to to each section of porters; the remainder of the baggage guard marched in a concentrated body in rear of the baggage. Then, in case of alarm, each section closed on its leading N.C.O., with whom marched the section of fours, and formed up round this little nucleus of regular soldiers. About half the porters were armed, and thus the section was capable of some defence, while the presence of even four soldiers gave them much greater confidence. In the one or two instances when this arrangement was tested by the enemy we found the porters stood their ground round the soldiers instead of bolting into the bush, as might otherwise have happened. While thus providing for the stiffness of our porter sections, the other half of the baggage guard was concentrated under a European officer, and ready to act against the flank of any ambuscade or stealthy attack.

During the march our flanking parties and scouts were generally furnished by the Waganda, who could get through the bush with far greater facility than our soldiers. They saved us from any general surprise, but, of course, could not always prevent a small party of the enemy creeping in and forming a local ambuscade. Still, as we could not wholly depend on our freedom from surprise, the order of our march was varied according to the general situation. If we were simply marching through a hostile country, and not in immediate touch with the enemy, our force was distributed as follows:—In front, 2 companies Soudanese and the Maxims, the Soudanese detailing a small advance guard; then came the baggage, with one company as baggage guard; and lastly came a rear guard of one company. In other words, we marched with half our strength in front and the rest so distributed as to provide against the contingency of an attack in flank or on our rear. If, however, we were in immediate touch with the enemy, and were advancing against him with the object of fighting, we had three-quarters of our force in front and the remaining company more or less concentrated to guard the baggage. It may appear that we attached undue importance to our baggage, but it must be remembered that as our Government force was small we had cut ourselves adrift from all communications, and thus carried everything with us. On one occasion when we expected a decisive battle we hastily made a small defensible zareba, into which we could put our stores and sick under a small guard, in order that we might have more men for the actual fight, for, of course, we did not dream of standing on the defensive.

Our men had been trained to certain formations which had proved suitable to the bush fighting, and were not contrary to the principles of the red book, though certain modifications were introduced. Thus all companies in front line were each formed in column of half-companies; on advancing to attack, each company extended its leading half-company into a loose rank entire, while the other half-company was kept concentrated as a local support, or, more properly, a local reserve. One company was generally kept back as a general reserve. In bush fighting you want lots of small local reserves, as gaps are likely to occur in your first line, not from the intensity of the enemy's fire, but from the nature of the bush.

You will observe that I have said nothing of the square or echelon formations which have proved so marked a feature of some savage wars, but you must remember that we had not to deal with the class of opponents who indulge in fanatical charges and hand-to-hand fighting. Our men had been through a short musketry course, but we did not trouble to teach them the adjustment of their sights for ranges over 500 yards, and, as a matter of fact, had seldom to fire at ranges over 200 yards, while often the shooting was at 10 or 15 yards in bush so dense that we could not see our foes.

A short description of our fort building may not be out of place. We all learn in our textbooks the principles of fortification, the necessity for a clear field of fire, for cover, and the other conditions that must be satisfied; but all of you who have practical experience of the application of these principles in the field will bear me out in saying that the ideal conditions are never obtained. Further, it is necessary to bear in mind considerations other than those of military engineering pure and simple. For if you have the strongest fort imaginable, satisfying the ideal conditions as regards field of fire, etc., and have no water, your garrison will be in a bad way.

The great thing is to obtain the best compromise you can, a compromise that enables you to fulfil as many of the recognized principles as possible. The general sequence of ideas that determined the construction of our forts in Unyoro was somewhat as follows:—The commanding officer decided in what localities it was necessary to have forts or fortified posts in furtherance of his general scheme, and, further, gave a more detailed idea of what each fort was intended to secure. Thus the fort at Kibero had to guard the salt works and secure a safe resting place for our steel boat, which constituted our sole effective occupation of Lake Albert. The fort at Kitanwa was merely intended to secure the food supply of Kibero, and, though thus fulfilling a subordinate *rôle*, required a larger garrison in order to do so. The fort at the Kafu had to protect the passage of the river, while that at Hoima was to contain the headquarters of the command in Unyoro, and was more of an administrative than a purely military centre.

Given the general and special idea, it remains to still further localize these ideas, taking into consideration the questions of food and water, and more especially of water supply. For, as I have before said, in a detached African fort, which is to be held by a small garrison, the water supply must be secure, and if not in the fort itself, must be commanded from the fort. It is frequently impossible to locate the fort, for other reasons, in a hole near the water, so we may consider it sufficient if the fort thoroughly commands its water supply. The food supply is not so important a factor, as we can store up reserves of food in the fort or send periodical convoys to it, while the storage of water is a more difficult matter. Nevertheless, we must clearly determine how the garrison is to be fed.

It does not always devolve on the military engineer to thus localize the special idea of the commanding officer, but before he selects a site he should fully understand what is wanted. For supposing that by accident the higher authorities have not sufficiently considered these points, and the fort is unfavourably placed, the military engineer is likely to find that the blame is supposed to rest on his shoulders.

We may dismiss the general idea, as that concerns the higher authorities, but bearing in mind the special idea and the question of water and supply, the military engineer has to consider the site, the nature of the work, including its size, its trace, etc., and the most suitable method of construction.

The question of water supply has reduced the choice of sites considerably in most instances, but still there are probably several possible ones. The one that fulfils most of the ordinary textbook requirements is generally the best, and *ceteris paribus* one with a good clear extensive field of fire is better than one more restricted in this respect. There are still considerations of climate, sanitation, drainage, etc. : I know one instance on which a site was suggested that appeared to be almost an ideal one, but was found to be under two feet of water for several months in the year ; fortunately this was discovered before the fort was actually built there.

Having selected the site, and in this one is frequently assisted or guided by a staff officer or higher authority, the next question is the nature of work required. This resolves itself mainly into a question of size, trace and profile, and obstacles. The first thing one generally discovers in these small African forts is that the honoured rule that the perimeter should be proportionate to the garrison at the rate of one pace for every two defenders will not work ; we cannot get our stores, huts, etc., inside the work at this rate. Thus we have either to stick to the rule and house our men outside, or increase the perimeter to get our men inside, and I need hardly say that the former method of dealing with the difficulty is not always expedient.

This brings us to the consideration of trace. Bearing in mind that the fort is, as a rule, theoretically too big for its garrison, we found a bastion trace the most suitable, as this enabled us to concentrate our defence to certain vital portions of the work. Thus we find all four of the Unyoro forts were quadrilateral enclosures, defended by bastions at alternate angles. The bastion trace proved very useful in Europe at the time of its institution, and the savage foes with whom we have nowadays to deal are considerably behind the Europeans of that date. If there seems any chance of the fort being rushed, it is well to make one or both bastions completely enclosed, and thus safe against an assault through the gorge if the enemy get inside the main work, in fact, of the nature of a keep. The size of the bastions is a matter of opinion. Our rule was one yard of flank for every ten yards of curtain to be defended. The profile is a minor consideration really, and depends on the armament of the enemy. In our case we had to deal with men armed with muskets and a small proportion of rifles. A thick parapet was unnecessary, and a mud wall or a wooden stockade answered our purpose. Earthworks in such cases are rather out of place unless no other material can be obtained. The parapet should be something more than a breastwork, and we endeavoured to secure a height of from 7 to 11 feet. Whether the fire was through loopholes or crenelations, or over the parapet, a banquette was required, and this we found was most easily made of wood, a sort of bench, 2 feet to $2\frac{1}{2}$ feet wide, on which the men stood to fire. This arrangement took up less interior space than any other, and did not tend to bulge out the stockade. We generally used both loopholes and crenelations for our bastions, and loopholes only for our curtains, as in the latter case there is less chance of any men manning the curtain being hit by a wild shot from the bastion, in case of night attack.

The provision of an obstacle is a most important consideration, more especially when the stockade or parapet is unavoidably low. All sorts of obstacles may be used, but it is well to bear in mind that the common thorn zareba can be easily destroyed by fire when dry. Pointed stakes, pits, thorn bushes or cactus hedges, fences and inundations, can all be used in certain cases, and no matter what the obstacle is, if it does not intercept the defender's bullets, and keeps the assailants exposed to fire for even a short time, it is of value.

At Kibero we wished a small fort to protect the boat and guard the salt works. A suitable site was found on a slight eminence within 30 yards of the fresh waters of Lake Albert, and flanked on one side by a small creek, which we converted into a harbour by cutting a proper channel and deepening the basin. In front lay a dangerous hollow which had formerly been an old salt working, but this proved a source of strength, as we diverted the Kibero stream into it, and made an inundation. Thus on only one side could the fort be attacked, and that side had a beautiful open field of fire. The fort was of the trace I have mentioned, each side being 12 yards long. The garrison was 40 men, and their huts were placed outside the fort, and between it and the water. The walls, for this was a mud fort, were $7\frac{1}{2}$ feet high, the bastions 10 feet high. All round the fort and the Soudanese quarters ran a stout wooden fence, against which was bound a dense mass of thorn bushes, and on the exposed face a second thorn zareba connected the inundation with the lake. As parts of the salt workings were invisible from the fort, a detached guard tower, 10 feet high, was placed on a small mound about 200 yards away. The garrison had three weeks' supplies in reserve in case of a siege, and were fed in ordinary times by weekly convoys from Fort Kitanwa, about $4\frac{1}{2}$ miles distant.

At Kitanwa the water supply was in a hollow, so the fort was located on a ridge which overlooked and commanded the wells. As it would have been dangerous to house the garrison outside in this case, the fort was made big enough to accommodate the garrison, and was about 40 yards square. It was of the usual bastion trace, but as timber was plentiful the parapet took the form of an 11-foot stockade. The bastions were large, and the flanks adapted for a double tier of fire. As the actual stockade was so high, no other obstacles were considered necessary. Two trees which came inside the enclosure were utilized, and crow's nests commanding an extensive view were constructed. This fort was held by 70 men, and commanded a large expanse of excellent cultivation. But in addition we stocked it with about 11,000 rations of grain, stored Unyoro fashion, in three underground chambers.

At Hoima we had another problem. It was estimated that the huts and accommodation required for the headquarters of the command necessitated an enclosure nearly 150 yards square. As at the same time Colonel Colvile wished that Captain Thruston should have at his disposal a moveable column of 150 men, this large fort must be capable of defence by the small garrison of 50 soldiers, plus a few armed porters and others. Accordingly I adopted the following design:— The enclosure proper was shut in by an open stockade, defended by two bastions. One of these was not much more than a guard-house, and was intended for about 20 men; the other was nearly 20 yards square, and was organized as a keep. As we could not rapidly get enough large timber to made a heavy stockade 10 feet high, the walls of the bastions were made of open stockading. To this were fixed horizontal beams on both sides, and the whole was filled in with clay plaster, made by mixing clay and dry chopped grass—a sort of magnified wattle and daub. When finished, the parapets presented the appearance of mud walls, difficult of escalade, and quite thick enough to keep out bullets. Elevated platforms for machine guns were made at the shoulders, and a crow's nest for look-out purposes was constructed in a tree. The site afforded a fairly good field of fire, and the fort was in a fertile district, three miles from Kabarega's capital, and within 200 yards of an excellent stream of water, which was completely commanded. This fort was attacked by the enemy, but Capt. Thruston, instead of adopting a defensive attitude, sallied out with his moveable column and defeated the enemy in the open.

The Kafu Fort was a small one of the same general design and type of construction as the keep of Fort Hoima, and was garrisoned by half a company. It was situated on a small hill, but as it had to command the causeway across the river, and its water supply, we had to sacrifice a little command and some field of fire in other directions. A good deal of clearing had also to be made. This fort was fiercely attacked by the enemy, who were, however, beaten off with heavy loss.

As will be seen from these examples, the nature of construction depends largely on the time at our disposal, and the materials and tools available.

Before closing, perhaps I should give some details of our bridging. Strictly speaking, it was more causeway making than bridge making, and it was only suitable to comparatively shallow rivers with a very sluggish current. At the same time, it was no inconsiderable job to make causeways like those over the Kafu River, one 400 and the other 900 yards long. The river was covered by a growth of papyrus, and this proved of great use, for we had to clear the bridge site, and the papyrus thus cut came in handy for fascines. In the shallower portions of the channel the roadway was simply made by cross layers of fascines. When the water was deeper we had to get down a substratum of timber. We did not attempt to make trestles—that would have taken too long. We threw in bushy tree tops, retaining the trunks to be afterwards used as beams, to be laid on the substratum thus obtained. Once we had got in sufficient tree tops to give us sufficient points of attachment, tree trunks and poles were lashed across to support the roadway; on these came smaller poles as chesses, and the roadway was made, as before, of cross layers of fascines constructed from papyrus, elephant grass, and the leaves and stems of the banana. The Waganda were very skilful at this sort of work, and these causeways, though thus roughly constructed, frequently proved serviceable for months, with little or no repair.

I trust that this short account of the Unyoro Campaign of 1893–94, even though it introduces no new ideas, may prove interesting to my brother officers.

PAPER II.

JOURNAL OF THE SIEGE OPERATIONS AGAINST THE MUTINEERS AT DELHI IN 1857.

EDITED BY COLONEL H. M. VIBART, R.E.

INTRODUCTORY NOTE.

THE original of the "Journal of the Siege Operations at Delhi in 1857" is amongst the papers of the late Colonel Baird Smith, C.B., Bengal (Royal) Engineers, A.D.C. to the Queen, and with the consent of his widow, Mrs. Baird Smith, has been placed at the service of the Royal Engineers Institute at Chatham for publication, as it was conceived that the proceedings of the Royal Engineers in that important event, which presaged the utter collapse of the Sepoy Revolt, should be permanently recorded at the headquarters of the Corps. The journal was carefully written up, day by day, from the 8th June, 1857, the date on which General Sir Henry Barnard, K.C.B., siezed the noted position on the ridge to the N.W. of the City of Delhi, when he drove the mutineers within its walls, until the arrival of the necessary siege train from Ferozepore, which soon after was utilized in knocking to pieces the walls on the northern face of the fortress.

The work of constructing the various siege batteries which were destined to put an end to the siege was very strenuous, and absorbed so much energy that no one had leisure or inclination to write, for everyone engaged had to devote himself to deeds alone, and those deeds must ever be considered as worthy of the highest admiration.

Nothing could surpass the gallantry and constancy with which all worked, and this record will, it is believed, serve to preserve for many a long year the grand devotion of the artillery and engineers, and, indeed, all the services, to their Queen and country.

During the first five weeks our small force, although its losses were heavy, sustained with success numerous attacks from the enemy. At this part of the operation we erected various batteries and other defensive works to enable our force to hold its position, but men were scarce, and the enemy's attacks so incessant, that insufficient working parties were available.

In the first four weeks it was several times proposed that the city should be captured by assault, by means of escalade and blowing in gates, but these plans were invariably postponed at the last moment, as it was thought the chance of success was too risky. The last one was intended to take place on 3rd July. When Colonel Baird Smith arrived, the force had increased in strength, and he proposed to the general that there should be an assault *de vive force*, but this again was negatived.

More systematic arrangements were then made for rendering the British position impregnable. First, by strengthening the whole in every feasible manner; and secondly, by destroying all the bridges in the neighbourhood which might be of use to the enemy while in no way serviceable for our operations. By the beginning of August this was duly effected, and our force was quite convinced of the fact that our position was absolutely safe from successful assault. Great attention was also given to the sanitary condition of the camp.

During August every preparation was pushed forward for the actual siege operations by the collection of sufficient materials in the engineer park, while the sappers and pioneers were practised in the construction of experimental batteries, and before the end of the month everything was ready, and the engineers only awaited the arrival of the siege train from Ferozepore.

This reached the camp on the 5th September, and the siege works were at once put in hand. The first step towards offensive operations may be considered to have commenced on 22nd August, when the left Pagoda trench was extended, and on 27th a battery for six light guns to sweep the ground between the "Sammy House" and the Shah bastion and Kabul gate was begun, so as to check the enemy in their attempts to hinder our siege works while in progress by sorties.

This battery had to be constructed on very rocky ground, rendering it very difficult to obtain the necessary earth, which had mostly to be brought from long distances in carts. This made the work very laborious and slow, so it was not until the night of 2nd September that the battery was completed.

On the 7th night the siege batteries proper were commenced, and by the 12th all were ready, and then commenced the final bombardment, although the first siege battery opened fire on the 8th.

On the 13th night the breaches were reported practicable, and on early morning of the 14th the assault was delivered.

This was generally successful.

Fighting went on, however, inside the city for five or six days, and it was not till the 20th that the mutineers were quite driven out of the city and the entire place became once more our own.

After the close of the original Journal on 5th September, the further various operations up to the capture of Delhi have been briefly added to make the record complete.

These notes have been compiled from official sources, and other details have been entered at the beginning to show who were the engineers employed on this almost unique siege, and to present rough estimates of the strength of the force at various dates, together with a statement giving the terrible losses from which those forces suffered.

Engineer Officers at the Siege of Delhi, 1857.

Engineer Officers at the Siege of Delhi 8th June to 20th September, 1857.

At the commencement of the siege 20 engineer officers were present, including Major Laughton, Chief Engineer.

Shortly before the end of June, Major Laughton was directed to return to the Punjab, and Capt. Taylor took his place as Acting Chief Engineer on 29th June, but only retained that post for 4 days, for on the 3rd July Lieut.-Colonel Baird Smith arrived as Chief Engineer.

By the close of July, 6 more engineer officers had joined, but 2 had died, and 1 was severely wounded. Lieut. Edmund Walker, having been wounded, died of cholera on 13th July, and Lieut. Edward Jones was struck by a round shot on 18th, and his leg was amputated; he lived for a few days, but died on 24th July. Lieut.

J. T. Walker was also severely wounded on 14th July. Thus, at the beginning of August, the total number of engineer officers was 23. During that month 5 more joined; but Lieut. Warrand was severely wounded on 31st August, and several others were ill, etc., so that on 13th September, although there were 27 officers in camp, only 19 were fit for duty, including the Chief Engineer and his Brigade-Major, Lieut. Chesney.

On the day of the assault 1 was killed (Lieut. Tandy) and 8 wounded (1 of whom died a few days after, Lieut. Salkeld), leaving only 10 fit for duty. The next day one of these was wounded, leaving 9 fit for work at the close of the siege.

Had the operations gone on much longer, there would have been no engineer officers available.

At the beginning of the siege there were 3 infantry officers acting as Assistant Field Engineers. One of these was killed (Capt. Greensill), shot by mistake by one of our own picquets. Another got sick and left on 17th July. Others were appointed from time to time, a second having to leave owing to sickness.

Altogether, 9 infantry officers officiated as Assistant Field Engineers, and of these 1 was killed, 2 had to leave camp owing to sickness, and 2 were wounded on day of assault.

During the whole siege, 4 engineer officers were killed and 16 wounded; and out of the 9 infantry officers employed as above shown, there were 5 casualties. Thus the total casualties in the Engineer Brigade amounted to 25 officers out of about 40.

Engineer Officers at Commencement of Siege.

Major J. Laughton, Chief Engineer. Recalled to Punjab 28th June. Now dead.

Lieut. (afterwards Major-General, C.B.) W. W. Greathed. Very severely wounded 14th September. Died 29th December, 1878.

Lieut. (now Lieut.-General) C. T. Stewart. Ill from 3rd September to close.

Lieut. (now General, Colonel-Commandant, C.B.) F. R. Maunsell. Wounded 14th September.

Lieut. P. Salkeld, V.C. Severely wounded 14th September, and died from effects of wounds 13th October, 1857.

Lieut. E. Walker. Wounded, and died of cholera 13th July, 1857.

Lieut. (afterwards Major-General, K.C.B.) G. T. Chesney. Severely wounded 14th September. Died 31st March, 1895.

Lieut. M. G. Geneste. Wounded. Died in 1858. Result of exposure during siege.

Lieut. (now Lieut.-General, C.B., A.D.C. to the Queen) Æ. Perkins. Wounded.

2nd Lieut. (now Major-General) C. S. Thomason. Ill from 11th September to close.

2nd Lieut. (afterwards Colonel, K.C.M.G.) J. N. Champain. Wounded. Died 1st February, 1887.

2nd Lieut. A. McNeile. Ill from beginning of August. Now dead.

2nd Lieut. F. S. Tandy. Killed during assault.

2nd Lieut. (afterwards Colonel) D. Ward. Now dead.

2nd Lieut. W. Fulford. Died in 1858 on way home, from results of exposure.

2nd Lieut. E. Jones. Severely wounded. Leg amputated on 18th July. Died from effects 24th July, 1857.

2nd Lieut. H. L. Carnegie (resigned after Mutiny quelled). Wounded 3rd September.

2nd Lieut. (now Colonel, V.C., K.C.B.) E. T. Thackeray.

2nd Lieut. (now Colonel) J. G. Forbes. Ill from 9th to 16th September.

Capt. (now General, G.C.B.) A. Taylor, Acting Chief Engineer from 29th June to 3rd July.

Lieut. (afterwards General, C.B.) J. T. Walker, Bombay Engineers. Severely wounded 14th July. In camp till 13th September, 1857, and then to hills. Died 16th February, 1896.

Lieut.-Colonel (afterwards Colonel, C.B., A.D.C. to the Queen) R. Baird Smith. Arrived 3rd July, and took up post of Commanding Engineer. Slightly wounded 12th August, but this did not in any way interfere with his work as Commanding Engineer, which post he retained till 23rd September. Died 13th December, 1861.

Lieut. (afterwards Major-General) H. W. Gulliver. Arrived 9th July. Sick from 29th August till close. Died 1897.

Lieut. (now Lieut.-General) H. A. Brownlow. Arrived 9th July. Wounded 14th September.

Lieut. (now Major-General) W. E. Warrand. Arrived 29th July. Wounded 31st August. Arm amputated.

Lieut. (afterwards Colonel) J. G. Medley. Arrived August 8th. Wounded 14th September. Now dead.

Lieut. (afterwards Brevet Major) J. St. J. Hovenden. Arrived August 8th. Wounded 14th September. Now dead.

Lieut. (afterwards Captain) P. Murray. Arrived August 14th. Wounded 15th September. Now dead.

Lieut. D. C. Home, V.C. Arrived August 21st. Engaged in blowing open Cashmere Gate. Killed 1st October, 1857, at Malaghur.

Lieut. (now Major-General, C.I.E.) J. S. Tennant. Arrived August 24th.

Lieut. (now Major-General, C.S.I.) R. C. B. Pemberton. Arrived September 1st.

Infantry Officers employed in Engineer Brigade.

At commencement of siege, Capt. T. M. Greensill, H.M. 24th, and Lieut. D. M. Martin were Assistant Field Engineers, and Lieut. Hill, 60th N.I., was attached to Engineer Park.

The first named was killed 22nd July, and the second left, ill on 17th. Ensign Chalmers was appointed 17th July. Ensign Gustavinski on 3rd August (wounded twice on 14th September). Ensign C. Anderson appointed 13th August (wounded 14th September). Ensign W. F. Nuthall appointed 14th August. Ensign F. Knowles appointed 20th August. Ensign H. Righy appointed 28th August.

Lieut. Hill went to the hills ill on 12th September.

At the time of the assault, 6 infantry officers were attached to Engineer Brigade, and 2 of these were wounded.

Lieut. Bingham, of the Pioneers, was mentioned in his despatch by the Commanding Engineer for his bravery in command of a party of the sappers in the assault.

Numbers of Troops Engaged at Siege from Time to Time.

Numbers of Troops at Delhi from time to time.

At the beginning of the operations at Delhi, the force only consisted of 500 to 600 sabres, 2,500 to 3,000 bayonets, and 22 field guns; total, less than 4,000.

At the end of June, the effective strength of the force was: artillery, 546; engineers, 575; cavalry, 956; and infantry 3,732. Grand total, 5,809.

On 10th July, the available force was 6,621. Artillery, 843; engineers, 688; cavalry, 843; and infantry, 4,079. The sick list contained 959.

On the 15th August, the force amounted to about 8,500, but probably 1,500 of these were sick. Artillery, 1,105; engineers, 722; cavalry, 1,299; and infantry, 5,353.

On the 11th September the effective strength was 9,866. In addition to these, there was the large number of 3,074 sick. Artillery, 1,350; engineers, 722; cavalry, 1,422; and infantry, 6,372.

Casualties in Different Arms of the Service.

Casualties in the Different Arms of the Service.

Engineers.

Effective on 11th September 722
Sick 214

936 of whom

4 officers and 40 men were killed.
18 ,, ,, 67 men wounded.

22 107
107

129 or 13·7 per cent.

Artillery.

Effective on 11th September 1350
Sick 257

1607 of whom

6 officers and 70 men were killed.
21 ,, ,, 267 men wounded.

27 337
337

364 or 22·6 per cent.

Cavalry.

Effective on 11th September 1422
Sick 618

2040 of whom

2 officers and 45 men were killed.
6 ,, ,, 98 men wounded.

8 143
143

151 or 7·3 per cent.

Infantry.

Effective on 11th September	6372
Sick	1985
	8357 of whom

33 officers and	828 men were killed	
83 „	„ 2224 men wounded.	
116	3052	
3052		
3168 or 37·9 per cent.		

Names of N.C.O.'s of Engineer Brigade.

Effective strength of infantry and cavalry on 11th September was 7,794, and the killed and wounded amongst these between 8th and 20th September 1,674, or 21·5 per cent.

The non-commissioned officers of Engineer Brigade were the following (44 in number) :—

The Sappers and Miners.

Stanton.	Lowell.	Hill.
Miller.	Candlish.	Fielding.
Sully.	Stewart.	McKenzie.
Hall.	Owen.	Allister.
Cantwell.	Carmichael.	Grierson.
King.	Worthington.	

Punjab Sappers.

Copeland.	Riley.
Kingsmill.	Swanson.
Stevens.	Willis.
Lester.	Robson.

Pioneers.

McGair.	Handy.	Williamson
Monies.	McCann.	Bonnett.
Ovens.	McGillivray.	Roy.
Hughes.	McKeon.	Cannell.
Vernal.	Hayes.	Simpson.
King.	Lynch.	Stevens.
	McNamara.	

Journal of the Siege Operations before Delhi.

The range of hills before the city having been carried, it was immediately adopted as the front of our position, and strong picquets were posted at the Flag Staff tower, at the Mosque, and at Hindoo Rao's house, each supported by 2 field guns; at the last post, the headquarters of the Goorkhas were also established. June 8th, 1857.

About 3 p.m. the enemy attacked the right of our position in considerable force, in loose order, sheltered by the great cover of gardens, enclosures and houses, but was immediately driven back on the picquets being reinforced.

Immediately on our placing troops on the hills the enemy opened a very well-directed fire on it from 2 24-pounders, 1 on the Cashmere bastion and 1 on the Moree bastion. The troops were too fatigued for any definite operations this night, but it was determined, in consultation with the Brigadier Commanding the artillery, to erect 2 batteries for an 18-pounder and 8-inch howitzer at Hindoo Rao's house to silence the enemy's fire.

A working party of 2 officers, 4 European N.C.O.'s and 20 sappers commenced work about 9 p.m. under the Field Engineer of the night; the pioneers, being late in reaching camp, did not come to the works till past midnight. 1st Night, 8th—9th. 1st Relief, Lt. Salkeld, 6 p.m.—6 a.m.

"Salkeld's" battery, for 1 18-pounder and 1 8-inch howitzer, and "Wilson's" battery for the same armament, were commenced; the former was available, the guns mounted, and fire opened from it on the Moree bastion in the morning, and the latter was brought up to about 3 feet.

Working parties of 30 sappers, 2 engineer officers, under direction of Field Engineer. "Wilson's" battery finished, and guns placed in position—the 8-inch howitzer on the Cashmere gate, the 18-pounder on a round bastion between Moree and Cashmere gates, where the enemy had placed a gun *en barbette*. A mortar battery ("Maunsell's") for 2 8-inch howitzers was commenced and rendered practicable. 2nd Relief, 6 a.m.—noon, Lt. Geneste.

One mortar laid in "Maunsell's" battery.

The fire being hot, and the reliefs few, owing to the whole of the pioneers having been on duty, the work proceeded slowly. 3rd Relief, noon—6 p.m. Lt. Perkins.

Remarks.

The enemy's fire was very steady and well directed, and, being of heavier ordnance than ours, the long ranges, the situation of the batteries, was disadvantageous, and but little effect was produced on the enemy by our fire. Several casualties occurred from round shot, one being an European sapper.

The enemy again attacked our right flank in great force, but was beaten back with heavy loss. It was evident that our position would be greatly strengthened by our holding the heights on the right of the Grand Trunk road, but our limited means rendered such a length of front impossible.

2nd Night, 9th—10th June. 1st Relief, Lt. Thomason 2nd Relief, Lt. Salkeld.

Another gun portion was added to the left of "Salkeld's" and "Maunsell's" battery for an 18-pounder each, aligned on the Cashmere bastion, and nearly finished by daylight. These were continued during the day. Casualties, 1.

3rd Night, 10th—11th June.

The mortar battery was made practicable for 2 mortars, which opened fire; a 24-pounder captured from the enemy was also placed in position on the right of "Wilson's" battery, to reply to a heavy gun opened by the enemy the day before from the Burn bastion, which enfiladed the position. A trench was also dug 6 feet wide, and 3 deep communicating between "Wilson's" battery and the enclosure of Hindoo Rao's house. The enemy's fire much more subdued, especially from the Cashmere bastion.

4th Night, 11th—12th June. Lts. Stewart, Geneste, Perkins.

Embrasures were repaired which had suffered from the fire. A traverse with a splinter-proof magazine was constructed on the right of "Wilson's" battery. The walls to the left of the mortar battery were banked up to afford greater protection. A traverse made to the right of "Maunsell's" battery.

In the morning the enemy attacked the whole of our position, and nearly surprised two guns at the Flag Staff, but they were driven back with great loss. Sixty sappers, under Lieut. Geneste, employed in the batteries, made a gallant charge, and drove a large party of the enemy away from their neighbourhood; 3 men were wounded on this occasion. Metcalfe's house on our left front occupied by 5 companies of infantry and 1 troop of cavalry. Another mortar battery ("Perkins'") was commenced on the left of "Wilson's" battery.

5th Night, 12th—13th June, Lts. Thomason, Stewart, Salkeld.

Two 8-inch mortars placed in position in "Perkins'" battery. Enemy has thrown up earthworks to protect his guns *en barbette* in the Cashmere and Moree bastions; his movements in the Burn stion cannot be distinctly seen. Fire very quiet. An attack ade again on our right, but easily repulsed.

A very hot fire from the Moira, Cashmere, Shah and Burn stions (one gun each) was kept up during the early part of the ening. The enemy also brought up some light guns to the crest our right, almost enfilading our position. Supported by this, ey made another attack in skirmishing order, and, as usual, was aten back. 6th Night, 13th—14th June. Lt. Salkeld.

A howitzer was placed in position without any platform during e night, which sent a few shells at enormous ranges, some even aching to the fort. The firing during the morning was as sharp usual, but slackened during the day.

No definite plan of attack being decided on, our operations were ll confined to repairing our batteries and keeping them in efficient ler. The firing of the enemy slack during the night, but heavy in e morning from 2 guns in the Cashmere and 2 in the Shah bastions, ich, however, only wounded 2 men, owing to the better protion now afforded. In the morning the enemy attacked in force h on the right and left, but without much energy; they were ily repulsed. Working parties very weak during the night, the ater part of the force being employed in collecting materials. traverse was made to protect the archway of Hindoo Rao's house, l a magazine commenced on the right of "Maunsell's" mortar tery. 7th Night, 14th—15th

Two pioneers and 4 artillerymen wounded in the trenches.

At night a trench of communication was made between "Salkeld's" l "Wilson's" batteries revetted inside with stones; the soil ng very rocky, the work was one of great difficulty, and proceeded wly. The principal working party was employed in entrenching mound on the right of Metcalfe's house for infantry, and in clearaway the jungle from the front of it. The enemy very quiet all ht and day, and no attack on the position. 8th Night, 15th—16th June.

The principal strength of our small working parties was told off improve the entrenched mound by Metcalfe's house. A strong able entrenchment for 200 infantry was prepared, and a comncement made of a mortar battery for 2 mortars in front of tcalfe's house, which, however, was discontinued at daybreak, at 9th Night, 16th—17th June.

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the request of the officer commanding the artillery. At the batteries only a small party was employed, who completed the demolitions of the wall in rear of "Maunsell's" mortar battery, and in extending the trench between "Wilson's" and "Salkeld's" batteries—a very tedious task. The enemy was observed during the day working at a battery above the bank of the canal, in the suburb of Paharipoor. Our mortar practice on it was excellent, but as, if the enemy were allowed to bring guns on our position for even a few minutes, the fire would probably be very disastrous, they were dislodged in the afternoon by 2 small columns of infantry under Majors Reid and Tombs, with 4 guns, in a very gallant manner, the battery destroyed, the suburb destroyed, and 1 gun (the only one found) captured.

Lieut. Perkins accompanied the columns as Field Engineer, and Lieuts. Fulford and Jones, with 40 sappers, executed the demolitions.

10th Night, 17th—18th June.

To-night a battery for 3 guns (1 18-pounder, 1 24-pounder, and 1 8-inch howitzer) was commenced about 300 yards from Hindoo Rao's house on the edge of the crest, with a view of commanding the ground before the town, along which the enemy's sorties generally advance, and of preventing any working parties of the enemy from erecting batteries in Paharipore.

Not a spadeful of earth was procurable anywhere near the site, the soil being pure rock, so that the progress was excessively slow.

A working party of 50 men in 3 reliefs was furnished from the line, but the men were too exhausted from their own exertions during the day to be of much service. By an oversight, too, no "bheesties" (water-carriers) accompanied the men, which rendered them still less fit for the labour of trenchwork. During the day a small party of sappers were employed in continuing the battery, but the enemy opening a smart fire on it, much could not be done.

11th Night, 18th—19th June.

To-night another working party of 150 men was supplied, but a party of them came again without their "bheesties." Our own party consisted of 150 pioneers and 30 sappers, 50 pioneers being taken away to construct an enormous traverse covering the door of Hindoo Rao's house, through which the previous day a chance shot had passed, killing 9 and wounding 7.

During the night the battery and epaulement was raised to a height of 5 feet on the left and 6 feet on the right; the rocky terreplein was levelled with the jumper for the reception of the gun platforms.

One sapper was killed and 1 severely wounded during the day, the working parties being incautiously exposed at the time of relief.

A large force with 6 guns moved from the city during the afternoon, and taking up a position among the gardens about $1\frac{1}{2}$ miles in our rear, opened fire; a smart action followed, but the night coming on before the infantry got into action, the enemy was not dislodged effectually.

The enemy being out in force, a party of about 150 men threatened an attack on the new ("Johnson's") battery, which was defended by the working party of 30 sappers only. However, they did not get beyond a musketry fire. Every day shows that, though the position of their battery is excellent for artillery practise, its advance beyond proper support, and the great expenditure of labour in making it, renders the advantage of its erection very questionable. 12th Night. 19th—20th June.

A working party of 20 sappers and 100 pioneers was employed on the battery during the night, who brought the left gun portion up to a thickness of 13 feet. A 24-pounder was brought into position, which opened fire on the Shah bastion in the morning. Fifty men were employed at "Reid's" traverse, covering the entrance to Hindoo Rao's house.

The troops off duty moved out at daybreak and drove the enemy from their position with ease, but had hardly returned back to camp when the latter returned to their gardens, and opened fire again, the round shot coming into camp. The force again advanced, and this time drove them completely away. Altogether about $\frac{1}{6}$ of the small force (about 600) engaged on our side were killed and wounded. Three officers were among the former, and 2 (Col. Becher, Q.M.G., and Capt. Daly, Commanding the Guides) were wounded. During the day the enemy kept up such a hot fire on our 1 gun in "Johnson's" battery from the Cashmere, Shah and Burn bastions that but little work could be done; the rocky surface was partially levelled for a second gun. The industry and coolness under fire of Corpl. Jenkins, of the Sappers, was highly praised by the Field Engineer on duty. 13th Night, 20th—21st June.

During the night a party of 100 pioneers and 30 sappers was employed on "Johnson's" battery. The ground for the centre platform was got well in hand, but great difficulty being found in removing the rocky irregularities they were filled in with earth, which, by raising the height of the platform, necessitated the revetment being also raised.

A party of 100 pioneers constructed a breastwork $3\frac{1}{2}$ feet high, with a running length of 200 feet revetted with fascines, in rear of our camp, commanding the village of Azadpore, behind which 2 18-pounders were placed. One pioneer killed by a shell.

14th Night, 21st—22nd June.

During the day the breastwork noted above was completed by an epaulement 85 feet long, and a small magazine was made at "Johnson's" battery, the platform for the middle gun was laid, and the right gun portion raised higher and thickened. The second gun was brought into position, and the third into the battery ready for its platform.

The enemy very quiet all day and night. A party of sappers under Lieut. Salkeld destroyed the bridge carrying the Grand Trunk road over the Nujuffghur Jheel; 325lbs. of powder was applied in three charges, and effected complete demolition of pier and both arches. The bridge was a native one, 60 feet wide, and of great thickness.

15th Night, 22nd—23rd June.

During the day the battery ("Johnson's") was completed and the third gun placed in position. A very quiet day. At night a party of sappers under Lieut. Maunsell, accompanied by Lieut. Jones, demolished the two remaining bridges over the Nujuffghur Jheel, viz., that by the canal aqueduct, and the one carrying the Rohtuck road. These demolitions, which were quite successful, completely prevent the enemy from advancing with artillery beyond the Nujuffghur Jheel except by a very long detour, and so the security of our rear is greatly increased.

16th Night, 23rd—24th June.

NOTE. — This was the Centenary of the Battle of Plassey.

The threatened attack of the enemy took place this morning. The effect of the demolitions of the night before was shown by the inability of the enemy to get his artillery (which came up to it immediately after Lieut. Maunsell's departure) across the Nujuffghur Jheel drain. Their attack was consequently confined to the right of our position. They occupied the Subzeemundee, and tried to carry "Johnson's" battery, but were driven out of the former by our infantry; immediately, however, on our evacuating the suburb, it was occupied by the enemy, giving our troops the task over again. They also brought out 3 light guns into Paharipore which took our position at Hindoo Rao's in flank, and gave us great annoyance. Our troops were ordered to take the guns, but were so exhausted by the heat, and the whole day's fighting that they were unable to attempt it. At night the enemy retired, taking their field guns with them. Their loss was estimated at from 500 to 800; on our side 1 officer was killed, 3 were wounded, and 156 men placed *hors de combat*. During the night 10 sappers and 120 pioneers were employed in strengthening "Johnson's" battery, and making better protection from musketry on its right flank.

During the day 20 sappers under Lieuts. Carnegie and Forbes effected the demolition of one of the sides of an enclosure in the Subzeemundee which the enemy had held on the previous day, and in trying to carry which a large proportion of our loss had occurred. Several large breaches were also made in the large serai on the other side of the Grand Trunk road. 17th Night, 24th—25th June.

At midnight 20 sappers and 180 pioneers were employed in strengthening "Johnson's" battery. This laborious work may be considered as complete. A quantity of the jungle in front of the battery was cut.

In consequence of the severe losses sustained by the 2 field guns posted at Hindoo Rao's house whenever they were brought into action on the occasion of any skirmishes, a battery for guns (2 9-pounders) was commenced this night by a party of 200 pioneers under Lieut. Champain. This was made in two detached portions, one in advance of the other, so as to leave a passage along the road upon which the battery was constructed. The battery was made with wide embrasures to give the guns a wide range, and with a musket-proof traverse on the right. The ground was very irregular, and the work a difficult one. 18th Night, 25th—26th June.

A breastwork for 2 field guns at the Mosque was also commenced this night, but little work was executed, the carts for carrying earth from cantonments to the rocky site of the battery not being forthcoming by mistake.

To-night a party of sappers under Lieut. Thackeray commenced demolition of houses in Subzeemundee on the right flank of "Johnson's" battery. 19th Night, 26th—27th June.

At the batteries another dismounted howitzer was laid in a battery ("Mackenzie's"), and at night a party of 2 Europeans, 5 sepoys and 120 pioneers completed "Champain's" battery, adding a traverse on the right rear portion of it.

20th Night, 27th—28th June.

The enemy made another sortie in the morning, attacking the Metcalfe picquet and our right. The former attack was easily driven back with small loss on either side; on the right they were beaten with a loss of about 50 killed and wounded on our side, and a supposed very heavy one on theirs. Subsequently to the affair it was determined to hold the Mosque and Serai in the Subzeemundee, and Lieut. Forbes and 30 pioneers, with 2 European N.C.O.'s, commenced loopholing them.

During the night the Mosque breastwork was made 9 feet at bottom, and a strong party with 400 sand-bags were employed in strengthening "Johnson's" battery, which had suffered during the day from the enemy's fire. News brought in that the Bhagput bridge had been burnt by the Jheend force in fear of an attack from a detachment of mutineers from Delhi.

It having been reported that the rebels were trying to fill the fort ditch with water from the canal, a party of 4 European and 20 native sappers under Lieut. Champain was despatched at 4 p.m. to the Poolchudder aqueduct, which carries the canal over the Nujuffghur Jheel drain, to turn the water off. No powder being available, Lieut. Champain effected his object by cutting through the high bank of the canal above the aqueduct and diverting the water into the Jheel drain. The greater part of the discharge was thus turned.

It having been determined to hold that part of the Subzeemundee which covers the right flank of "Johnson's" battery, a party of 30 pioneers under Lieut. Forbes commenced at night loopholing the serai and dewala there.

21st Night, 28th—29th June.

A very wet day. But little firing on either side. In the batteries no new work was done.

At daybreak a strong party of sappers and pioneers, with elephants, under Lieut. McNeill, was employed in strengthening the post in the Subzeemundee, establishing good flanking protected fire, and destroying the cover in the neighbourhood. The work was continued by Lieut. Tandy with 30 pioneers in the 2nd relief.

In order to prevent the entry of water into Delhi, and to render the masonry bed of the aqueduct (Poolchudder) impracticable for guns, Lieut. Stewart, with 20 sappers, proceeded at 4 p.m. to effect a demolition by gunpowder. As a strong stream was running down the Nujuffghur drain, Lieut. Stewart selected the end arch of the aqueduct, which was dry, for his operations. The space between the pier and abutment was filled with earth close to the soffit; two barrels of powder were then placed together in the middle of the arch, and tamped with earth. The effect of the explosion was to shatter the arch without bringing it down. This insufficient result was probably due to the imperfect tamping, which was done rapidly, that the party might return at daylight.

During the 1st relief Lieut. Thackeray, with 10 sappers and 100 pioneers, with elephants, continued the destruction of enclosures round the Subzeemundee post. A small party of sappers under Lieut. Jones, with elephants, cleared an opening through walls and trees to the right front of the General's mound, so as to lay open about 300 or 400 yards of the Grand Trunk road to the fire of the guns on the mound. 22nd Night, 29th—30th June.

At night 30 sappers were employed in strengthening and extending the epaulement to the right of "Johnson's" battery.

Capt. A. Taylor joined to-day, and was appointed Acting Chief Engineer, vice Major Laughton, who was recalled to his duties as Superintending Engineer in the Punjab.

In the morning the enemy attacked our right, keeping clear, however, of our retrenchment in the Subzeemundee. The 4th Sikhs and Goorkhas were smartly engaged in the open. All the casualties among the 2nd Fusiliers (Bengal), who held the Subzeemundee, were occasioned by men exposing themselves. In the afternoon a column under Brigadier Showers pushed through Kissengunj and Paharipore to capture the 3 field guns which the enemy had brought out during the day, but they marched through the whole suburb without finding either guns or enemy. During the night the batteries were altered to bring the fire of the 3 left guns of "Wilson's" battery, the left gun of "Salkeld's" battery, and the centre gun of "Johnson's" battery, all to bear on the Shah bastion, making, with the left gun of "Johnson's" battery, and the 2 guns of "Salkeld's" battery, a total of 8 guns directed on that bastion. 23rd Night, 30th June—1st July.

The platform of the centre gun of "Johnson's" battery, on being shifted, was found to be too close to that of the left gun, and the centre gun could not, consequently, be used till the next night, when the embrasure was altered.

24th Night, 1st—2nd July. Ordinary work at the batteries.

25th Night, 2nd—3rd July. Every arrangement was made for an assault this evening, but was put off at the last moment. At night a large party was employed in strengthening our right, cutting the brushwood in front, etc. "Champain's" battery was also altered into one of three light guns.

26th Night, 3rd—4th July. *Lieut.-Colonel Baird Smith, Chief Engineer to the Force, arrived to-day.*

The enemy were seen leaving the city in large numbers, with guns and cavalry, passing our right by the heights near Eedgah.

Our efforts during the day directed to strengthening our right by a breastwork for infantry between the Subzeemundee and "Johnson's" battery, and in felling brushwood. At night a small party improved the defence of the Metcalfe house advanced picquet, upon which an attack was expected the next morning.

About midnight firing was heard in the direction of Alipore, and a column under Major Coke, consisting of Coke's Rifles, with part of the 8th and 61st Queen's, some cavalry, and 12 guns, was immediately ordered. Lieuts. Salkeld and Thomason accompanied the column with a party of sappers for the purpose of destroying the Haidarpore bridge.

27th Night, 4th—5th July. During the day 80 pioneers strengthened the Subzeemundee and ground between it and "Johnson's" battery; along the latter a musketry-proof breastwork of stones was commenced, the flanking defences of the Serai were improved by sandbag traverses, and the destruction of the walls in its vicinity continued.

At night 50 pioneers, under Lieut. Fulford, constructed 230 feet of musketry breastwork, extending from the left of the Metcalfe stables (our left advanced post towards the bank of the river).

In the morning of the 4th our column came upon the enemy retiring from Alipore, after having looted the place; a desultory action ensued, which resulted in their retiring. But little loss occurred on either side, the most serious to us being the death of an excellent native officer of Major Coke's regiment.

28th Night, 5th—6th July. During the day and night the ordinary repairs to the batteries were conducted, and the demolition and felling of trees in the Subzeemundee continued.

At night 70 pioneers, under Lieut. Tandy, continued the trench on the left of the Metcalfe picquet, but the rainy weather prevented it being quite completed.

Major-General Sir H. Barnard, Commanding the Field Force, died in the afternoon of cholera.

Major-General Reid, C.B., Acting Commander-in-Chief, assumed charge of the Field Force.

During the day a bed was laid for a dismounted howitzer. At night the usual repairs. 29th Night, 6th—7th July.

A large quantity of saltpetre was discovered by Lieut. Perkins in Kissengunj, at what was apparently a powder manufactory, and was brought into camp.

The trench at the front Metcalfe picquet was widened, and the parapet made shot-proof during the night.

During the day Lieuts. Greathed and Fulford, with 30 pioneers and 30 sappers, proceeded along the canal and destroyed the Shalimar, Badlee and Shumapore bridges. The bridges were all of wooden superstructure, and the demolitions were effected by small charges of powder shaking loose the girders, which were then easily removed from their position, and hauled up to the bank on this side ready to be removed to camp.

The experiment was made of laying the dismounted howitzers on wooden sleepers, with a backing of strong timbers 12 inches thick; the bed answered very well, and prevented the howitzers from being imbedded as before, but the recoil of the gun cracked every piece of timber that was placed in rear. Firing from city very slack all day. 30th Night, 7th—8th July.

Thirty sappers and 30 pioneers, under Lieuts. Chesney, Champain and Geneste, proceeded with a strong column to demolish the Bussye bridge, the only remaining one over the Nujuffghur Jheel canal. The demolition was successfully accomplished, and the column returned to camp at 2 p.m. No trace was found of the enemy, who it had been hoped, would meet us there. 31st Night, 8th—9th July.

In the batteries the inconvenience noted before of the recoil of the dismounted howitzer destroying the timbers in rear of the platform was remedied by using buffers, so that the cascabel no longer impinged on the wood.

Lieuts. Stewart and Carnegie, with 20 sappers and 30 pioneers, dismantled the two remaining bridges over the canal between Delhi 32nd Night, 9th—10th July.

camp and Alipore (Paimbaree excepted), piling the timber superstructure on the bank, and levelling the pier and abutments to the water's edge. Lieuts. McNeill and Jones, with a similar party, effected a demolition of two arches of the Poolchudder aqueduct, which had been unsuccessfully attempted before by Lieut. Stewart.

In the morning a party of the enemy's cavalry made a rush from the right rear flank through a part of our camp, inflicting some damage. They escaped with a loss of about 20 killed. Early in the day the enemy attacked our right in very great force; they were beaten back, and followed up close to the walls. Their loss was estimated at 800; ours was 228 killed and wounded, the heaviest we have had in any battle. The Guides and Goorkhas were the principal sufferers; the 8th Queen's were also hotly engaged.

The fire in the batteries was too hot to permit of much work being done, and the night was too rainy for effective repairs. A small magazine was made at the General's mound by Lieut. Fulford.

Lieut. Gulliver, with 300 Punjab sappers, and Lieut. Brownlow, with 600 pioneers, arrived to-day.

33rd Night, 10th—11th July.

During the day the defences of the Subzeemundee were continued. A strong working party was posted at the Mosque between the Moree bastion and "Johnson's" battery, to render it a good musketry post, but a fire was opened on it, and 8 of the pioneers were wounded almost immediately, when the party was withdrawn.

34th Night, 11th—12th July.

One hundred pioneers were employed all day, under Lieuts. Brownlow and Geneste, entrenching the right flank between the General's mound and the Nujuffghur Jheel, the open ground by which the cavalry came into camp on the 9th was cut across by a trench, the line of wall up to the General's mound was renewed where broken down, the walls in front of the picquet were broken, the garden walls either side of the Grand Trunk road were broken down, and the gardens partly cleared of brushwood and trees.

The "Sammy House" was entrenched, and batteries repaired.

35th Night, 12th—13th July.

The defences on the right flank were continued. The Subzeemundee Serai defences were renewed where injured by rain.

A trench was lined out from the right rear of the advanced picquet house (Sammy house) towards the Subzeemundee Serai. About 60 yards of this was made during the night. A party of Sikh sappers collected the wood taken from the different dismantled bridges, and brought it down the canal partway towards the Paimbaree bridge.

During the day ordinary repairs to batteries and work at the "Sammy House," which the enemy allowed to continue almost uninterruptedly. 36th Night, 13th—14th July.

The defences on the right flank were continued, and a breastwork for 2 field guns and some infantry was made on the bank to the right of the General's mound. Lieut. Edmund Walker, of Engineers, died on evening of 13th from cholera; deeply regretted.

A strong party at 3 a.m. started construction of a battery ("Taylor's") of sandbags on the right of "Perkins'" mortar battery for 2 field guns to command the ground to the left of the "Sammy House," a screen of gabions being placed in front of the battery to hide the pioneers; they were permitted to finish it unmolested, which they did by 11 a.m. 37th Night, 14th—15th July.

An attack from the enemy took place to-day, which lasted from morning till about 6 p.m. Our people at first remained quiet behind their cover, and suffered very little loss, but were at last advanced to drive the enemy away, which they did, pursuing them close to the gate of the city. The enemy then opened with grape from the walls, and our troops, in returning, suffered severely. Our loss was 209, and 15 officers were wounded, including the Adjutant-General, Brigadier-General Chamberlain, and 3 officers of Engineers, Lieut. Walker severely, and Lieuts. Geneste and Carnegie slightly.

At night 80 men employed in strengthening the "Sammy House," upon which there had been a heavy fire during the day.

Right Flank.—100 pioneers employed during 2nd relief. Abattis constructed across road to Subzeemundee on left of right picquet, leaving space for field guns. The slope of the ramp up to the field-gun breastwork ("Greensill's") was lengthened, and sandbags placed for loopholes on crest of parapet. Some walls, easy for cavalry, were staked.

The road to the Subzeemundee was altered and improved. Some brushwood at the gardens was cleared.

Subzeemundee and Pagoda Picquet.—All available hands were employed in strengthening this post, improving the trench, and making the wall of the pagoda shot-proof. Batteries were repaired. 38th Night, 15th—16th July.

Right Flank.—17 men, all that were left, sharpened the stakes of the abattis on Subzeemundee road.

39th Night, 16th—17th July.

Subzeemundee and Pagoda Picquet.—500 pioneers employed in thickening breastwork at the Pagoda, and making a traverse and in improving the whole of the breastwork on the right. Some walls were destroyed, and trees cut down in front.

Batteries repaired, and magazine made for "Taylor's" battery.

Right Flank.—120 men continued the removal of brushwood near the Grand Trunk road—the ramp up the "Greensill" breastwork strengthened, and the ditch on extreme right deepened.

Metcalfe Picquet.—120 men constructed a ditch in front of the Cow-house to give the loopholes a command, and cut down a quantity of jungle in front of the post.

40th Night, 17th—18th July.

Subzeemundee and Pagoda Picquet.—150 men employed in strengthening Pagoda breastwork and loopholing it for musketry, and clearing jungle in front of it.

A party of Major Coke's corps raised the breastwork between "Johnson's" battery and the "Crow's Nest."

Batteries.—Some platforms were re-laid. The magazine in "Taylor's" battery was completed. An epaulement was commenced on left flank of "Johnson's" battery, but the fire on it compelled the working party to desist during the day.

During the night a trench was commenced between "Perkins'" mortar battery and "Taylor's" light gun battery. An epaulement for howitzers to the left of "Johnson's" battery was partly made.

Right Flank.—150 men employed in clearing the gardens near the Grand Trunk road, and in commencing the drainage of the right rear of camp.

Metcalfe Picquet.—An officer and 40 men were employed during the night in ascertaining the truth of the supposed existence of an enemy's mine under the stable. The noise of what appeared to be men at work below it was distinctly heard by several persons, but ceased on our party commencing to sink a shaft in the stall of the stable where the noise was heard.

41st Night, 18th—19th July.

Subzeemundee and Pagoda Picquets, or Front and Right Defences.—20 sappers employed during day making a roadway to enclosure on right of "Salkeld's" battery, and in strengthening parapet in front of the sunken howitzers left of "Johnson's" battery.

150 pioneers during day on breastwork connecting "Perkins'" and "Taylor's" batteries, and in cutting down trees in front of Pagoda picquet.

During day another attack was made on our right, which continued for some hours. Our men suffered but little loss while behind their breastworks, most of those hit being struck by shots from the Subzeemundee taking them in reverse. In afternoon, a column under Brigadier Jones, advancing, drove them out of the Subzeemundee and Trevelyan Gunj, and returned to camp. Our loss was 13 killed and 71 wounded; among the former Lieut. Crozier, of 75th.

100 pioneers of the night relief employed in improving the right angle of the parapet of the Pagoda picquet, and completing the breastwork just outside the door. Demolition of walls and cutting of trees could not be carried on, as no covering party was available.

Batteries.—20 sappers employed in repairs of "Johnson's" and the left batteries, but were quite unequal to the work required.

Left Front and Right Rear Defences, with Camp Work.—150 pioneers continued the main drainage trench, which enters the Nujuffghur Jheel cut 100 feet above the Cemetery bridge.

50 pioneers cut jungle to the front, but were withdrawn on the enemy's fire opening out at the Subzeemundee.

Front Mosque Picquet.—180 pioneers completed Mosque right gun breastwork, and commenced on infantry breastwork connecting batteries; but little was done to this work, as the officer in charge had reached too late to observe where earth could be obtained.

Metcalfe Picquet. — 80 Punjab sappers under Lieuts. Gulliver and Fulford continued enquiry to ascertain the truth of the report that mining was going on under the post. The shaft ordered to be sunk by the Chief Engineer, Lieut.-Colonel Baird Smith, reached a depth of 14 feet; but nothing was discovered, and the impression left on the minds of the officers was that the sounds heard proceeded from work being carried on at the bridge of boats.

Subzeemundee Serai and Pagoda Picquet.—350 pioneers improved the Serai parapet. An adjoining building occupied by the enemy during his last attack knocked down. As many houses as possible in the village demolished and cleared, so as to be untenable by the enemy. 42nd Night 19th—20th July.

Front of Pagoda picquet further cleared of trees, etc.; the parapets raised and thickened. Traverse similarly treated, till work had to be suspended owing to enemy's fire.

Batteries.—40 sappers under Lieut. Ward repaired the embrasures.

Camp Drainage.—200 pioneers extended the main drain, nearly completing it to its vertical section.

43rd Night, 20th—21st July.

Subzeemundee Serai and Pagoda Picquet.—N.B.—Owing to a change in the working hours of the Engineer Brigade, the day's work closes at 5 p.m., and this journal on this night is brought up to 5 p.m. 21st.

100 sappers, 80 Punjab sappers, and 450 pioneers employed in continuing Subzeemundee Serai parapet. Sandbags added to incomplete portions. Clearance of houses and jungle about the post extended. Pagoda picquet parapet and traverse continued. The dome of the Pagoda partly removed. Traverses added to Goorkha breastwork, where some men were killed on 20th by reverse fire.

Batteries.—All repaired, and additional security given to magazines of "Wilson's" battery by a bank of stones and earth being placed in front of it.

Metcalfe Picquet.—150 pioneers half-finished a breastwork enclosing rear of post.

Camp Works.—Main drain finished. Two tanks tapped and water drawn off very satisfactorily. Extension of drain going on.

44th Night, 21st—22nd July.

Subzeemundee Serai and Pagoda Picquet.—50 sappers, 80 Punjab sappers, and 430 pioneers effected extensive demolitions, and removal of cover for the enemy near Subzeemundee post. Great clearance of trees, etc., on road leading to canal bridge to bring the ground under the guns. Pagoda post parapet raised. Traverse nearly finished. Dome of Pagoda successfully demolished. Breastwork of Pagoda provided with a return flank, as Major Reid has found it to be too extensive to be all held satisfactorily.

Batteries.—Right battery repaired and epaulement worked at.

Metcalfe Picquet. — Rear breastwork completed, very much improving the defences of that post, and placing them in a most satisfactory state. Rear breastwall entirely revetted with stone, except one top course of fascines. An abattis established at end gate of the park and the rear gate of the garden opposite Ludlow Castle. The barrier near Major Coke's camp completed. Mosque road repaired.

Camp Drainage.—Drain from Jheel to No. 1 tank nearly completed. Tanks Nos. 1 and 2 ran out all day and are nearly dried.

Subzeemundee Serai and Pagoda Picquet.—Clearance of trees, etc., towards the canal continued. A sandbag parapet on small adjoining Pagoda completed. 45th Night, 22nd—23rd July.

Parapet and traverse at Pagoda picquet completed. A gabionade at the "Crow's Nest" was completed, and three platforms for Coehorn mortars cleared. The fire of the enemy this morning was directed with great precision on parapet of Pagoda picquet, and the party clearing jungle, and at the Serai were driven in by the enemy. The wall of the Observatory in rear of the left battery strengthened.

Batteries.—General repairs.

Metcalfe Picquet.—Abattis which had been made for prevention of a sudden attack by cavalry was removed by an advancing party of 75th.

Left Front Defences.—Four flêches and a prolongation to the left of the left Mosque breastwork were commenced, which will command the ground between the Flag Staff and the Mosque.

Drainage of Camp.—Cut from Jheel to No. 1 tank 670 feet long and 6 feet deep in progress.

Gabions and Fascines.—230 men made 122 gabions and 82 fascines.

Subzeemundee Serai and Pagoda Picquet.—30 sappers and 450 pioneers clearing at Subzeemundee and continuing gabionade for a light mortar battery at the "Crow's Nest" post. Clearance down to the canal well done, and a clear view of the road along which the enemy's cavalry pass on occasion of attack is now opened up. 46th Night, 23rd—24th July.

Batteries.—35 sappers repaired "Johnson's" and the 3 light gun batteries, the latter of which had been almost demolished.

Front and Rear Defences.—250 pioneers cleared trees in front of the guns on the General's mound, and in completing the Mosque breastwork and flêches.

Camp Drainage.—Continued with 50 pioneers.

Gabions and Fascines.—250 men made 183 gabions and 40 fascines.

A party of 20 sappers under Lieut. Gulliver completed arrange ments for blowing up Paimbaree bridge should such be necessary.

Lieut. E. Jones died this morning (24th) of the wounds he received on 18th.

Subzeemundee Pagoda and Serai Picquet.—450 pioneers made extensive clearance in front of and on the flanks of Serai picquet post. 47th Night, 24th—25th July.

Defiladed and strengthened both flanks of Pagoda picquet post, raised and added to the traverse, carried a banquette along the face of the whole of the parapet, and parapet itself strengthened Gabionade for the protection of the Coehorn battery completed with exception of some fascines at top. The enemy was seen to be employing working parties in Paharipore, but the precise nature of the work unknown.

Batteries.—30 sappers and 50 pioneers strengthened howitzer epaulement at "Johnson's" battery, and executed general repairs to "Wilson's" and "Salkeld's" batteries.

Poolchudder Dam.—120 pioneers completed a temporary dam in the canal to stop the retrogression of level of the bed.

Gabions and Fascines.—240 men made 153 gabions and 100 fascines.

48th Night, 25th—26th July.

Subzeemundee Serai and Pagoda Picquet.—A practicable road for artillery opened from the place to the canal bridge on the right. The Serai heretofore occupied by the enemy demolished, and the trees inside cut down.

At the Pagoda picquet a traverse for the protection of the room in which part of the men sleep was completed. The great traverse on right of the post materially heightened, and the drainage of the courtyard effected. Breastwork between Observatory and Mosque continued, and 130 feet in length finished.

Batteries.—The lines of fire of the centre battery were altered so that one embrasure should bear on the Moree, a second on the Cashmere, and the third on Ludlow Castle. The whole of the parapet, from 9 feet from the centre embrasure, had to be thrown back and re-made. This was very nearly completed with gabion and fascine revetment by 4.30 a.m., and was finished in the succeeding relief. Obstructive trees removed from front of left battery, and petty repairs of batteries done wherever required.

Camp Drainage.—Continued with 50 pioneers.

Gabions and Fascines.—240 men made 177 gabions and 63 fascines.

Detached Parties.—Lieut. Gulliver and 20 sappers at Azadpore. All reported perfectly quiet, and no apparent attempt to renew the Rohtuck road and Bussye bridge.

Lieut. Tandy and 20 sappers for bridge demolition busily employed on the bridges between Bhawana and Nitowla.

Lieut. Greathed and 40 sappers for the complete demolition of the Rohtuck road bridge. This was satisfactorily accomplished. The whole bridge, abutments and piers are now destroyed, the gap exceeding 60 feet. The canal dam at the Poolchudder has been turned by the stream, and will be repaired as soon as practicable.

Subzeemundee Serai and Pagoda Picquets.—Heavy rain fell during the working period, and not much work was done. The clearance round the fort was, however, continued, and the interior defences at the Pagoda picquet were made stronger and more complete. 49th Night, 26th—27th July.

Breastwork between Observatory and Mosque was continued.

Batteries.—Requisite repairs executed.

Left Front Defences.—Flag Staff breastwork was improved.

Camp Drainage.—New drains being cleared out, the earth being employed in making a new raised road. Another main drain from the rear of the artillery lines to the Cemetery to be commenced.

Gabions and Fascines. — 270 men made 147 gabions and 102 fascines. Work interrupted by want of brushwood.

Detached Parties.—Lieut. Gulliver and 20 sappers at Azadpore. All perfectly quiet.

Lieut. Tandy and 20 sappers demolishing bridges on the canal above Bhawana escape. A small bridge completely and a large bridge partially destroyed.

Right Front and Flank Defences.—25 sappers and 450 pioneers employed. Field powder magazine made at Coehorn battery. Subzeemundee Serai parapets repaired and interior drained. Pagoda picquet small traverse completed and general repairs made. Shelter for men in batteries in progress. Breastwork between Mosque and Observatory continued; about 200 feet in length will complete the whole. 50th Night, 27th—28th July.

Left Front and Rear Defences.—150 pioneers employed. Abattis at Metcalfe picquet, opposite Ludlow Castle, replaced. Drainage in rear of camp continued.

Detached Parties.—Lieut. Gulliver and 20 sappers at Azadpore. All quiet, no appearance of enemy, and no preparations for repair of Rohtuck road and Bussye bridges.

Lieut. Greathed reports that, having visited the Rohtuck road bridge by daylight, he found that the destruction of that work had been most complete. A causeway might be constructed with great difficulty, but crossing by surprise is quite impracticable. Jheel drain and canal having risen, have both good volumes in them.

Gabions and Fascines.—400 men made 261 gabions, and 124 fascines.

Right Front and Flank Defences.—110 pioneers employed. The Serai drainage completed, and the sandbag parapets and traverses re- 51st Night, 28th—29th July.

paired. The breastwork at Pagoda picquet altered and improved. The ground in front of the centre battery cut away to enable the guns to fire on the ground 300 yards in their front.

The pioneers completed a small hut in "Champain's" battery for the shelter of artillerymen.

Left Front and Rear Defences.—340 pioneers employed. Lieut. Stewart with 140 pioneers demolished the Aqueduct bridge, and re-established the retaining dam across the canal near the same point. The dam was made of large logs of wood let into the banks on both sides, and protected by stonework and clay. 200 pioneers employed on drainage works in rear of camp.

Detached Parties.—Lieut. Gulliver and 20 sappers at Azadpore. All quiet, and the bridges remain intact and unvisited.

Lieut. Tandy and 20 sappers returned from Jutowlie, having completed the dismantling of the wooden, and the demolition of the masonry bridges, between that place and Bhawana.

Gabions and Fascines.—330 men made 247 gabions and 102 fascines.

52nd Night, 29th—30th July.

Right Front and Flank Defences.—220 pioneers employed. The Serai picquet parapets and those of small pagoda behind it repaired. Some more of the houses, with a few trees, near the post should be cleared away. Some more shelter erected for shelter of men in the batteries. Left flank of left battery provided with embrasures for 2 guns.

Left Front and Rear Defences.—250 pioneers employed. Abattis at lower gate re-established. Bridge on main road to Metcalfe's stable picquet repaired. Side road bridge renewed. Circular breastwork provided with a sandbag parapet. Abattis between circular and right breastwork strengthened. Barriers near Coke's camp repaired. Dam at Poolchudder aqueduct found to be passable for cavalry and guns. Immediate alterations ordered.

Gabions and Fascines.—500 men made 378 gabions and 125 fascines.

53rd Night, 30th—31st July.

Right Front and Flank Defences.—20 sappers and 100 pioneers employed. Rain being very heavy, and the enemy turning out, not much work was done. The extension of the left battery was, however, completed. Traverses and parapets of Pagoda picquet strengthened. Batteries repaired as far as rain would permit.

Left Front and Rear Defences.—200 pioneers employed. Canal dam made impassable for guns and cavalry by driving large piles across the canal.

Detached Parties.—Lieut. Warrand and 20 sappers at Azadpore. The enemy moved out in this direction and re-crossed the Jheel drain in some force, but as their bridge seems to have failed, their proceedings are not vigorous. Lieut. Gulliver and 280 Punjab sappers employed in battery practice to train the men to the work.

Gabions and Fascines.—250 men made 53 gabions and 111 fascines.

Right Front and Flank Defences.—Heavy rain having caused the sandbags in Serai breastwork to rot and give way, new ones were substituted in part. Buildings in Subzeemundee unroofed and timber obtained removed to park. Batteries repaired and parapet made for riflemen on right of "Champain's" light battery. 54th Night, July 31st—1st August.

Left Front and Rear Defences.—Drains in rear of camp which are not yet complete severely tried by heavy rain, but their beneficial effect was very evident, as without them the camp must have become a vast swamp. Some drainage was effected at the Metcalfe picquet.

Detached Parties.—Lieut. Warrand continues to watch at Azadpore. The mine in the bridge has not suffered from the rain.

Gabions and Fascines.—400 men made 201 gabions. Work very short owing to failure of brushwood.

Right Front and Flank Defences.—360 pioneers employed. Subzeemundee Serai and Pagoda defences repaired. Trees between Serai and the Mound being cut away. The night and morning attack of the enemy interfered with the working parties and prevented them doing much work. Such repairs as could be made to the batteries were carried out, and arrangements made for making the men at the Observatory picquet more comfortable. Hindoo Rao's house repaired and strengthened. 55th Night 1st—2nd August.

Left Front and Rear Defences.—280 pioneers employed. Mosque breastwork completed. It now affords cover for 4 field guns and 150 men. There is cover for 200 between Mosque and Flag Staff, and for 80 at latter point. Drainage works continued. Trench for infantry made in the bank between the Mound battery and picquet. Roadways of camp bridges repaired.

Detached Parties.—Lieut. Lang with 12 sappers at Azadpore. All quiet. Whole country described as a great swamp, over which cavalry can pass only by having practicable routes pointed out to them, and artillery not at all.

56th Night, 2nd—3rd August.

Right Front and Flank Defences.—60 sappers and 360 pioneers employed. Right battery repaired. Embrasures revetted and parapet strengthened by raising outer edge of superior slope. Damages sustained by the sandbag loopholes in Pagoda picquet repaired. Breastwork leading from Pagoda picquet towards Serai raised and thickened. Trees cut down and cover destroyed between this breastwork, and the Grand Trunk road, of which the enemy took advantage in his last attack. Room at Pagoda picquet, the wall of which was breached by enemy's shot, protected. "Champain's" battery repaired, and left epaulement of right battery raised. Stone floorings for the tents of the Rifles made. Centre and left batteries repaired. Some new platforms laid, and sundry windows at Hindoo Rao's house blocked up, etc.

Left Front and Rear Defences.—250 pioneers. Drainage on right and left of Metcalfe stable picquet completed. 200 men employed in main drainage of camp. A good deal of brushwood for gabions, etc., cut.

Detached Parties.—Lieut. Stewart with 12 sappers at Azadpore. Found the general depth of water in the Jheel drain about 6 feet, and the country generally in a most impracticable state. Canal supply a full one. The dam stands well as yet, and is in no present danger.

57th Night, 3rd—4th August.

Right Front and Flank Defences.—40 sappers and 280 pioneers. Jungle and walls in front of Pagoda picquet cleared away. Repairing exterior wall of the same, damaged by enemy's fire. Parapet in front of work thickened. Epaulement of right battery repaired. Subzeemundee Serai parapet put in order. General repairs of batteries, etc. All the engineers on duty at this post have reported the offensiveness of the smell from the dead bodies in front of Pagoda picquet.

Left Front and Rear Defences.—150 pioneers employed exclusively on the main drainage of the camp.

Detached Parties.—Lieut. Stewart with 12 sappers at Azadpore. All quiet at the Rohtuck road and Bussye bridges, and the depth of water at these works, in their neighbourhood, at the canal dam, reported satisfactory.

Lieut. Carnegie and 120 pioneers employed in raft making for demolition of enemy's bridge. 58th Night, 4th—5th August.

Gabions and Fascines.—200 men made 150 gabions and 62 fascines.

Right Front and Flank Defences.—160 pioneers. Right battery repaired. Front wall of house in Pagoda picquet made shot-proof. Garden walls on right of Grand Trunk road broken down, and mounds sloped off to destroy cover. Wall in front of left battery knocked down, and platform laid in the same. Tiles being collected for Mosque picquet.

Left Front and Rear Defences.—120 pioneers. Drainage of camp continued. Unsuccessful attempt made to destroy enemy's bridge by sending explosive machines down stream against it. Three such machines were sent off; one exploded prematurely, having caught in some bushes on an island; one stranded and did not go off at all; the third was lodged against the bridge, but not exploding, was taken out by two of the enemy's men on mussucks. Three more (on the plan of the one that exploded) are ready to be sent off. The large raft will be reserved till after the next fall of rain, the river being now rather too low. Leakage stopped and other repairs of the Cowhouse roof at the Metcalfe picquet going on.

Gabions and Fascines.—400 men made 228 gabions and 361 fascines.

Right Front and Flank Defences.—40 sappers and 130 pioneers. Clearance of brushwood in front of and about Serai picquet towards Grand Trunk road. Enemy's fire stopped the work. Such work as was possible at batteries was done by the sappers. 59th Night, 5th—6th August.

Left Front and Rear Defences.—40 sappers and 80 pioneers. Cowhouse picquet roof repaired, props for beam ready, and leakage stopped. Some more explosive machines in progress, and the large raft going on under Lieut. Ward.

Detached Parties.—Lieut. Salkeld with 12 sappers at Azadpore. All quiet. Depths of water satisfactory. There is a footpath over the ruins of the aqueduct. Lieut. Salkeld thinks the Rohtuck road bridge passable by cavalry, one or two at a time, though with great difficulty. This appears to the Chief Engineer to mean that, for military purposes, it is not in reality passable at all.

Gabions and Fascines.—592 men made 460 gabions and 447 fascines.

Right Front and Flank Defences.—40 sappers and 180 pioneers. 60th Night, 6th—7th August.

Subzeemundee parapet again repaired, it having been a good deal damaged. "Champain's" and "Johnson's" batteries repaired. Left and centre batteries partially repaired, and wall in front of left battery further broken down. The enemy having opened a sharp fire on pioneer working party employed on the wall, it was withdrawn.

Left Front and Rear Defences.—No work required.

Detached Parties.—Camp road. 200 pioneers repairing road from camp to Azadpore. Lieut. Salkeld with 12 sappers at Azadpore. All quiet.

Gabions and Fascines.—405 men employed only during the morning, as long as the brushwood lasted. Made 179 gabions and 116 fascines.

61st Night, 7th—8th August.

Right Front and Flank Defences.—60 sappers and 450 pioneers. Mortar battery for 4 8-inch mortars commenced, but work not satisfactory. One pioneer was killed and 4 wounded in commencing this work. Left embrasure of right battery repaired. The others could not be touched by reason of the heavy fire maintained from them during the night. Two of the sappers employed wounded. Conversion of 3 light gun battery into a 2 heavy gun one partly completed, and 1 heavy gun placed in position. Parapet and loopholes of Pagoda picquet repaired. The embrasures of right battery had become so large at noon that it was essential to repair them at once temporarily with sandbags. This was done by a party of sappers, the havildar in charge of which greatly distinguished himself by his zeal, activity and intrepidity. One sepoy (since dead) was wounded by a round shot. Serai picquet parapets put in order.

"Salkeld's," "Wilson's," "Taylor's" and "Perkins'" mortar batteries repaired, and in some instances re-revetted.

Left Front and Rear Defences.—130 pioneers. Cowhouse post repairs nearly complete. Experimental battery being demolished.

Detached Parties.—Lieut. Salkeld with 12 sappers at Azadpore. All quiet. Water in Jheel decreased about 2 inches only.

Gabions and Fascines.—355 men made 288 gabions and 296 fascines.

62nd Night, 8th—9th August.

Night.—Mortar battery ("Warrand's") completed with exception of magazine.

"Champain's" battery converted into one for 2 24-pounders.

Day.—Mortar battery completed. The enemy kept up a very smart fire all day, chiefly from Paharipore, with light guns. One sapper killed by a round shot. Pretty steady musketry fire on "Sammy house." 150 men on Azadpore road. 300 men collecting brushwood. 300 men making gabions.

Night. — Part of breastwork on right of Pagoda picquet strengthened by a gabionade 40 feet long. The men not being able to work outside from the sharp skirmishers' fire, this was not made shot-proof. Parapet leading from "Johnson's" to "Champain's" battery continued. Two sappers and 2 pioneers wounded. 63rd Night, 9th—10th August.

Day.—Continued fire of light guns and skirmishing.

Night.—Magazines of right batteries had sloping roofs given to them. Embrasures were strengthened by vertical posts, two on each side at the sill, and 5 feet towards the mouth to retain the fascine revetment. Mosque breastwork was strengthened, and extended Lieut. Fulford with 120 pioneers attempted to throw up an embankment outside the stable wall of Metcalfe's picquet, but were a good deal hindered by enemy's fire, which killed 1 and wounded 3 pioneers. 64th Night, 10th—11th August.

Day.—Three $5\frac{1}{2}$-inch mortars placed on the Mound to reply to the enemy's light guns, but the range was too great to enable them to be at all useful.

Night.—Pagoda picquet behind Serai picquet provided with new parapet of sandbags. Traverse for protection from musketry commenced between "Johnson's" and "Champain's" batteries. Lieut. Gulliver and 200 pioneers attempted to continue the outside embankment of the stable at Metcalfe's, but the enemy's fire prevented anything being done. 65th Night, 11th—12th August.

Day.—At dawn a column consisting of

350 1st Fusiliers,
100 2nd Fusiliers,
100 8th Queen's,
100 75th Foot (from Metcalfe picquet),
300 Coke's Corps,
100 Kumaon Battalion,
100 4th Sikhs,

total 1,150,

with cavalry and 6 guns in support, moved down to Ludlow

Castle to capture the 2 field guns which had been annoying us from the front of the stable. The operation was successful, 4 light guns being seized on the road by Ludlow Castle, many of the gunners bayonetted, and considerable loss inflicted on the enemy, but, probably owing to Brigadier Showers, who commanded, being wounded at the commencement, no move was made to take the 2 guns on the bank of the river, which had been firing all the previous day, and the picquet house, to destroy which a party of sappers under Lieuts. Maunsell and Hovenden had been attached to the column, was left untouched. Our loss was 19 killed and 93 wounded. Lieut. Sherriff, 2nd Fusiliers, was wounded mortally; Brigadier Showers and Major Coke severely; Capt. Greville and Lieut. Owen, 1st Fusiliers, and Lieut. Innes, 60th N.I., orderly officer to Brigadier Showers, slightly.

66th Night, 12th—13th August.

Night.—A trench with parapet constructed from the ravine in rear of the pagoda right breastwork to the breastwork. The right 40 feet of breastwork commenced to be made shot-proof. Mosque breastwork extended and thickened; a laborious task, as the earth has to be brought a long distance in carts. At Metcalfe's stables the left trench deepened and parapet thickened, and approaches from rear improved.

Day.—Azadpore road repaired.

67th Night, 13th—14th August.

Night. — Trench and thickening of breastwork commenced in previous night continued. Mosque traverse thickened, and continued. Metcalfe stables breastwork interior thickened, and work done to rear approaches.

68thNight, 14th—15th August.

During the day the enemy withdrew his light guns from the front of Metcalfe stable picquet, and his picquet. Scarcely any firing passed on the left. On the right matters were much as before. The traverses of stones in front of the windows of Hindoo Rao's house were completed.

There was no work at night on the 14th.

69th Night, 15th—16th August.

There being no obstacle, 150 Punjab sappers were employed in raising the embankment outside the wall of Metcalfe stable picquet, which was brought up to an average height of 7 feet. 150 men were employed strengthening the breastwork on right of Pagoda picquet.

Day.—Rather sharp fire from Paharipore guns, and one or two light ones in the morning. Our right batteries replied, and soon silenced them. The number of light guns out much less. 150 men brought wood from Subzeemundee. 200 men repaired Azadpore road.

Night.—100 Punjab sappers combined to strengthen breastwork to right of Pagoda picquet, and 100 heightened the gabionade between "Johnson's" and "Champain's" batteries, and made a wall in front of the magazine of the former to prevent shells rolling in. 70th Night, 16th—17th August.

Day.—Enemy very quiet, scarcely any artillery fire, and musketry but feeble. They could, however, be seen in force at Ludlow Castle, and apparently at work on some kind of entrenchment. Gabions, etc., 250 men. Brushwood, 370 men.

Night.—100 Punjab sappers continued to strengthen breastwork. The same number worked at the gabionade between "Johnson's" and "Champain's" batteries. From the darkness of the night, and the stony soil, the amount of work on this, and the previous, night was small. 71st Night, 17th—18th August.

Day.—Batteries very quiet. Slight musketry fire still continues. 150 men bringing timber from Subzeemundee. 200 men brushwood from Azadpore. 40 men repairing magazine.

Night.—No working parties. 72nd Night, 18th—19th August.

Day.—250 men brushwood in Subzeemundee. 200 men brush wood in Azadpore. 250 men gabion and fascine making. Quiet day. Little firing of any sort.

Night.—Reports having been received that Lieut. Hodson (who had gone in the direction of Rohtuck to watch a body of the mutineers supposed to have moved in that direction) was in difficulties and surrounded by superior numbers, a force of about 1,000 infantry of 4th Brigade, 200 Mooltanee horse, some Guides cavalry, and 6 guns under Major Tombs; the whole under Brigadier Nicholson, marched at 11 p.m. through pouring rain to relieve him. 73rd Night, 19th—20th August.

200 men were employed in raising and thickening the breastwork to the left rear of "Johnson's" battery to make a place for the erection of a shed to shelter the gunners, and a similar work for the men of "Champain's" battery. From the want of soil but little progress was made. During the night a battery for 2 light field guns was made in the trench on the left of the Metcalfe stable

picquet to batter down the picquet house of the enemy on the bank of the river in front of it.

Day.—General Nicholson's column returned, having found the road impracticable beyond Alipore. The light gun battery fired 120 rounds at the picquet house in front of it with but little effect. The enemy replied with a well-directed fire from Selimghur and the Moree bastion. But little firing all day.

74th Night, 20th—21st August.

Night.—100 Punjab sappers worked at the Pagoda picquet breastwork and 100 pioneers at the rampart to protect the gunners' shed in the right batteries. Two men were wounded by musket balls.

Day.—The sheds were continued. The enemy had placed 2 guns on the other bank of the river opposite Metcalfe house, and shelled Metcalfe park and Coke's camp. No casualties, but Major Coke had to move his camp further off.

75th Night, 21st—22nd August.

Night.—60 Punjab sappers worked at repair of breastwork on right of Pagoda picquet. 180 of them commenced the trench on the left of the Pagoda picquet; the soil proved rocky, and the work laborious. The enemy fired once or twice with grape, but did no harm. 50 pioneers strengthened the breastwork for protecting the gunners between "Johnson's" and "Champain's" batteries.

Day.—The enemy brought out 3 light guns, and about mid-day made a feeble attack on the centre battery, occupying the gardens below it, and firing up into the embrasures. They retired again in the afternoon.

76th Night, 22nd—23rd August.

Night.—200 men, in two reliefs, extended the left Pagoda trench. This may be considered the first step to offensive operations.

Day.—But little firing during the day. The enemy's guns from the other side of the river threw a few shot into the Metcalfe park, but did no harm. 50 Punjab sappers worked in the afternoon at widening the left Pagoda trench. 50 more pioneers joined the force.

77th Night, 23rd—24th August.

Night.—140 Punjab sappers worked at the trench, 40 men cut down trees in front of it.

Day.—Very wet. Capt. Taylor, with Lieuts. Medley, Home and Thomason, made a reconnaissance of the ground from the Pagoda picquet to Marshall's house. The enemy's skirmishers fired a good deal at the party, and one Goorkha was mortally wounded.

Instruction of workmen in the park under Lieut. Hovenden in laying platforms and forming magazines commenced.

Night.—190 men continued the trench on left of Pagoda picquet and cutting down trees, 50 being employed as a covering party. 78th Night, 24th—25th August.

Day.—General Nicholson, with about 2,200 men of all ranks and 12 guns, started at 4 a.m. to meet a body of the enemy, which it was understood had left the city the previous day for Nujuffghur with a view of coming on our rear. In the evening he came on them posted in strength in a village near Nujuffghur, and drove them from it with small loss, taking 13 out of about 16 guns they had with them. A good many men from Coke's corps, and the 61st were hit in trying to enter another village in which the fugitives had taken refuge, and which was walled and difficult of access. Here Lieut. Lumsden, Acting Commandant of the corps, was killed—a very excellent officer. Lieut. Gabbett, of 61st, was killed also, and Lieut. Elkington, of same regiment, and Assistant Surgeon Ireland, Horse Artillery, were severely wounded. Total loss about 60 killed and wounded. The rebels left all their camp behind them, and the plunder was very great. Lieut. Geneste and 30 sappers destroyed the Nujuffghur bridge after the action, though still under a heavy fire.

Night.—200 men were employed in cutting down trees, etc., in front of the Pagoda left trench. 79th Night, 25th—26th August.

Day.—In the afternoon the rebels attacked our right, bringing out 6 guns. Apparently they supposed that the main body of our troops had gone out with the column. About 50 sowars had the temerity to ride up within 50 yards of our centre ("Salkeld's") battery, when they were soon repulsed by the Minie rifle. Our casualties were only 12 in this affair.

General Nicholson's column returned at dusk.

Night.—200 men worked at the left trench. 80th Night, 26th—27th August.

Day.—A battery for 6 light guns was marked out in the Pagoda left trench, and 120 men went down at noon to commence it. The enemy fired a good deal at our working parties, but without doing any harm, and our batteries kept their fire under.

Night.—80 men continued the new battery without being annoyed. 81st Night, 27th—28th August.

Day.—100 men continued the battery during the 1st and 2nd reliefs. The enemy opened a sharp fire on the working parties from the city, but with bad practice, causing no casualties.

82nd Night, 28th—29th August.

Night.—20 men employed in forming the parapet of the half-moon breastwork at main picquet into a battery for light guns.

Day.—This was continued during the day. In the 2nd relief 60 men worked at the new battery. The soil is here as rocky as usual, and the labour required for a work of the kind enormous. A good deal of firing during the day.

83rd Night, 29th—30th August.

Night.—300 Punjab sappers under 8 officers (4 went up first, and 4 at 9 p.m.) were told off at evening to clear the brushwood in front of the new trenches and "Sammy house." A covering party of 100 men first drove off the enemy as far as their own breastwork, and kept them from re-occupying it again till evening. A sharp musketry fire was opened at intervals, and grape from the walls, but a satisfactory amount of work was done. There were a few casualties among the covering party, and 5 of our men were hit.

Day.—80 pioneers continued the battery. During the day 4 sappers were hit working on the parapet of the new battery by shell from Shah bastion; 1 was killed, and 3 dangerously wounded. Lieut. Warrand, Field Engineer on duty, was also dangerously wounded by a shell while laying out an embrasure. His arm was amputated close under the shoulder.

84th Night, 30th—31st August.

Night.—No working parties.

Day.—60 men sent to the new (6 light gun) battery. Assistant Surgeon T. H. Woodward, attached to the brigade, died this day.

85th Night, 31st August—1st September.

Night.—100 men were employed on new battery.

Day.—150 men employed on 1st relief. Two embrasures were pierced in "Johnson's" battery to bear on Moree bastion, that the guns in it may be used if necessary in that direction as a diversion in ulterior operations. One sapper was killed and 2 wounded by a round shot coming through the embrasure while they were at work. A shell from the other side of the river bursting in the Metcalfe stable killed and wounded 9 men. These were the first casualties that have occurred from this battery. Lieut Pemberton arrived.

Night.—100 men at new battery. An experimental battery was made in camp, the solid up to the sole of the embrasures being built solid of fascines. This part was done in about $1\frac{3}{4}$ hours, but although there was a double row of diggers (one 40 feet in rear of the parapet), scarcely one-third of the earthwork was done by morning. The diggers were dead beat by midnight, and did little afterwards. 86th Night, 1st—2nd September.

Day.—100 men made traverses in Metcalfe picquet. 100 men worked at new battery.

Night. — 50 men commenced cutting trees in front of main picquet. 100 men finished the 6-gun battery. 100 men completed the traverse, Metcalfe stables picquet. 87th Night, 2nd—3rd September.

Day.—At 2 p.m. Lieut. Ward, with 100 pioneers, commenced to cut trees between main picquet and towards Ludlow Castle, to clear the ground on the left flank of proposed battery No. 1. They were not molested.

Night.—150 men under Lieut. Tennant were sent down to construct a battery for 2 light guns on the right of 6-gun battery to fire across the front of the "Sammy house," but the fire was too hot to enable any work to be done. A road for light guns was made to the 6-gun battery. 50 men under Lieut. Thackeray continued the cutting down of trees. 88th Night, 3rd—4th September.

Day.—A magazine was commenced for 6-gun battery, but made very little progress in the stony soil.

Night.—150 men under Lieut. Geneste commenced the 2-gun battery. 60 men with 2 officers continued the cutting down of trees. 89th Night, 4th—5th September.

[*The Original Journal of Siege Operations ends here.—The continuation has been compiled from Official Documents*].

The siege train arrived from Ferozepore.

There were now 60 siege guns available, with a plentiful supply of ammunition.

Abstract of Siege Guns.

Description of Ordnance.	In Position or Park.	Siege Train from Ferozepore.	Total.
24-pounders	5	6	11
18-pounders	11	8	19
10-inch howitzers	11	2	2*
8-inch howitzers	2	4	6
10-inch mortars	2	4	4
8-inch mortars	6	4	6
5½-inch mortars	12	4	12
Totals	36	24	60

* From Phillour.

6th Sept. Preparations made for commencement of offensive operations. The battery to prevent sorties from Lahore and Cabul gates, and to assist in keeping down fire of Moree bastion, was quite ready for use.

NOTE.—Armament of batteries previous to 7th September, the day on which the siege works proper were commenced :—

Hindoo Rao's and Observatory.

Right battery ... ... 2 24-pounders.
Centre battery ..2 18-pounders and 2 8-inch howitzers.
Left battery... ...2 18-pounders and 2 8-inch howitzers.
Left mortar battery... 2 10-inch and 2 8-inch howitzers.
Mosque picquet ... ... 4 light guns.
Flag Staff ... ... 2 light guns.
Mound ... ... 2 light guns.
Rear... ... ... 2 light guns.

Total—2 24-pounders, 4 18-pounders, 2 10-inch howitzers and 6 8-inch howitzers, and 10 light guns.

7th Sept. General Wilson issued an address to the army manly, spirit-stirring and wise in the cautions it conveyed. Kaye says: "It is said to have been written by Colonel Baird Smith."

In evening No. 1 advanced battery, in two portions, was traced 700 yards from Moree bastion. It was known as "Brind's" battery, after the officer in command, Major James Brind, a most gallant and highly distinguished officer (afterwards Sir James Brind, G.C.B.) 7th—8th Sept.

By morning two portions finished and armed, though not ready to fire till nearly sunrise. For some time we were well pounded from Moree bastion, but as our guns got gradually into play the enemy's fire grew less, and was at length completely overpowered. It was armed with 5 18-pounders, 1 8-inch howitzer and 4 24-pounders.

No. 2 battery traced and commenced. 8th—9th Sept.

Ludlow Castle and Koodsia Bagh were occupied by strong detachments.

No. 2 battery was completed and partially armed, but not unmasked. Armed with 8 24-pounders, 3 18-pounders and 7 8-inch howitzers. 9th—10th September.

No. 3 battery was commenced on left for 8 24-pounders and 12 Coehorns.

No. 4 battery for 10 heavy mortars was completed in Koodsia Bagh, but not yet unmasked. The light mortars were afterwards worked from the rear of the Custom House.

No. 2 battery was strengthened, armed and unmasked, and No. 3 battery completed. The last made in the boldest manner within 180 yards of the Water bastion. 10th—11th September.

On 11th our batteries opened fire with exception of No. 3, which did not open till morning of 12th. Night and day the continuous roar of our 64 guns and mortars went on, pouring shot and shell on the devoted city, and warned the enemy that his and our time had at length come. 11th—12th September.

The breaches were examined by engineer officers at 10 p.m. Lieuts. Medley and Lang examined the Cashmere bastion, and Lieuts. Greathed and Home the Water bastion. Both breaches were reported practicable, and the Chief Engineer, Lieut.-Colonel Baird Smith, recommended that assault should take place early morn 14th. 13th Sept.

The assault took place early morn. 14th Sept.

The following was the distribution of the engineer officers :—

1st Column, under Brigadier-General J. Nicholson.

Capt. A. Taylor, B.E.	Lieut. Bingham (Pioneers).
Lieut. Medley, B.E.	Lieut. Lang, B.E.

Ensign Chalmers.

2nd Column, under Brigadier W. Jones, 61st Regiment.

Lieut. Greathed, B.E.	Ensign Gustavinski (Punjab Sappers).
Lieut. Hovenden, B.E.	
Lieut. Murray, B.E.	

3rd Column, under Brigadier G. Campbell, 52nd Regiment.

Lieut. Home, B.E.	Lieut. Tandy, B.E.
Lieut. Salkeld, B.E.	Ensign Nuthall.

4th Column, under Major C. Reid, Sirmoor Battalion.

Lieuts. Maunsell and Tennant, B.E.

Reserve Column, under Brigadier J. Longfield, 8th Regiment.

Lieuts. Ward and Thackeray, B.E.

The explosion party which performed the desperate duty of blowing in the Cashmere gate in broad daylight consisted of

Lieuts. Home§ and Salkeld§‡, of Engineers.
Sergt. John Smith§.
Sergt. Andrew Blair Carmichael*.
Corpl. J. Burgess, *alias* Joshua Burgess Grierson†.
(All of the Sappers).
14 Native Sappers and Miners.
10 Punjab Sappers and Miners.
Bugler Hawthorne§, 52nd Regiment.
Havildar Madhoo, Sappers, wounded.
Havildar Tiluk Sing, Sappers, wounded.
Sepoy Ram Het, Sappers, killed.

Subadar Toola, Jemadar Bisram, Havildar Ramtaroy, Sepoy Sahib Sing,	Specially mentioned for great gallantry.

15th Sept. Several mortars were got into position within the city to shell the town and palace.

* Killed.
† Mortally wounded.
‡ Wounded and died subsequently.
§ Obtained the Victoria Cross.

The magazine was stormed by H.M.'s 61st, Wilde's Punjabees and the Beloochees. 16th Sept.

Kissengunj evacuated by the enemy this morning, and 5 heavy guns captured.

Our right and left positions at Cabul gate and Magazine brought into direct communication by a line of posts in rear of which every thing was our own. The Bank, Major Abbott's house and Khan Mahomed Khan's house were captured, so that posts were now close to the palace and Chaudnee Chowk. 17th and 18th September.

All our mortars played on the palace and quarters of the city occupied by the enemy.

Burn bastion surprised and captured by a party from Cabul gate. 19th Sept.

Lahore gate and Garstin bastion taken and held. Camp outside Delhi gate captured. Also the Jumma Musjid. Palace gate blown in and palace taken, and the whole city was now in our hands. 20th Sept. Morning.

Lieut.-Colonel Baird Smith fixed the headquarters of the Engineer Brigade at Durriagunj, near the river, south of the palace, and, with his civil assistant, slept there that night. 21st Sept.

Lieut. Hodson captured the King of Delhi.

Lieut. Hodson captured two of the King's sons and a grandson, all deeply implicated in the atrocities committed in May. 22nd Sept.

They were shot by Hodson, and their bodies exposed for 24 hours in front of the Kotwali.

Delhi having thus been captured, Lieut.-Colonel Baird Smith, Commanding Engineer, left Delhi for Roorkee, and handed over the command of the Engineer Brigade to Capt. Alexander Taylor. 23rd Sept.

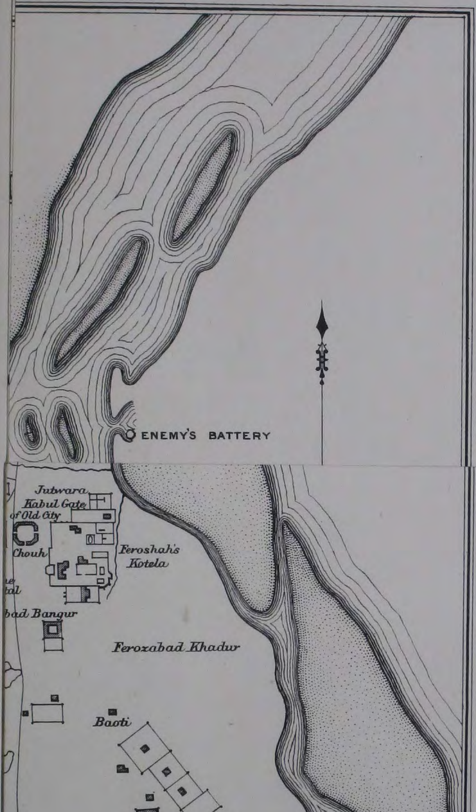
Extract from introduction to *Selection of Despatches, etc., Regarding Mutiny*, 1857–58, edited by George W. Forrest, Director of Records of the Government of India, 1893:—

"So ended this great siege, one of the most memorable in the annals of England. It lasted for more than 12 weeks,* and during that time the small force of besiegers fought more than 30 well-contested combats against a vast and disciplined host. Neither heat

* The operations at Delhi lasted from 8th June to 20th September, 1857, or 15 weeks.

nor rain nor pestilence destroyed their courage or crushed their spirits. In the men's tents they made merry, and, like the Greeks before Troy, they had their sports. Stricken to death, the soldier told his officer he would soon be up again, and be ready for a brush with the mutineers.

"These warriors, worn with disease, worn with constant duty under a burning sun, reduced in numbers, stormed in the face of day a strong fortress defended by 30,000 desperate men, provided with everything necessary to defy assault. The list of killed and wounded bears testimony to the intrepidity displayed by all arms of the service. The effective force at Delhi never amounted to 10,000 men, and 992 were killed and 2,845 wounded; total, 3,837. Many more died from disease and exposure. This loss recalls to memory some of the bloodiest in our military history. But the annals of the Peninsular and Crimean Wars can hardly afford a parallel to the slaughter at Delhi. The losses of the infantry at Delhi best illustrated the arduous nature of the service. The Rifles began with 440. Shortly before the storm they received a reinforcement of 200 men. Their total casualties were 389. The Goorkhas began 450 strong, and was joined by a draft of 90. Total casualties amounted to 319. The Guides commenced with 550, and casualties were 303. Of the artillery, who had done splendid service in heavy batteries, etc., 365 were killed or disabled. Of the engineer officers two-thirds, and of the engineer department 293, were killed or wounded. The returns bear testimony to the severe loss suffered, and the despatches record in simple and manly terms a tale of which Englishmen can never grow weary as long as they reverence deeds of valour. They set forth the indomitable courage and perseverance, the heroic self-devotion and fortitude, the steady discipline and stern resolve of English soldiers."



s along the ridge held by the British troops,

PAPER III.

FIELD ARTILLERY AGAINST A POSITION PLACED IN A STATE OF DEFENCE.

By Capt. J. Headlam, R.A.

Much honoured as I felt at being asked to lecture to you here, and particularly interesting as the subject you selected for me is, there are difficulties in my way which I never contemplated when I undertook the task.

I think my best way will be to first run over the duties of the field artillery of any attacking force; then to examine more carefully the probable effect of field artillery fire on the various general types of artificial defences; and to conclude with some reference to the probable effect on the question of the two new weapons which modern science seems inclined to force on us. I refer to high-explosive shell and field howitzers.

The first thing of all to remember is that the general principles of the action of field artillery must be followed, whatever defensive works the enemy may have indulged in. Tactical considerations come first—technical second. We gunners must first think of so employing our fire as to best support the tactical plan of the commander, just as the engineer in tracing his trenches must have ever before his mind the requirements of the army, not the theoretical possibilities of the ground. This fact is acknowledged; the necessity of referring to it is proved by many an example of useless artillery duels, and works which gave no strength to the army for which they were intended.

Let us then first see what are the duties of the artillery of an attacking force. They are simply summed up in our drill book as first the *preparation* and then *the support* of the infantry attack. Before this, however, batteries (of horse artillery especially) may be employed to drive in the enemy's advanced posts, or to discover his main position by drawing his fire. Great care must be exercised on such occasions, as if small bodies of artillery are pushed forward early without orders they may seriously interfere with the general's plan of action, and possibly bring on a premature attack. Against a prepared position such an attack will almost certainly end in disaster. Probably the best-known instance—though success was in this case eventually obtained—is the gigantic results that followed from the somewhat reckless use of the advanced guard battery of the V Corps at Worth.

But passing over such preliminary work, let us turn to the preparation of the infantry attack. It is now admitted on all sides that, except under very special circumstances, an infantry attack can scarcely hope to succeed if exposed to the fire of the enemy's artillery; the first duty, therefore, of the attacking artillery is to silence that of the enemy. During this period the general will be finally deciding on his plan of attack, and as soon as *he considers* the enemy's artillery fire sufficiently beaten down, the greater part of the guns will be turned on to the point or points he has selected for attack.

So far for the *preparation* of the infantry attack. It consists, you see of—

1. Overcoming the enemy's artillery.
2. Shelling the point selected for attack.

When the defence at this point is sufficiently crippled and demoralized by this concentrated fire, the general will order the advance of the infantry. Directly this order is given every gun, regardless of the fire from the enemy's artillery, should be at once turned on to the point of attack, and on to any troops which may take the infantry advance in flank. As the infantry move forward it becomes the duty of the artillery to support them as closely as possible without further orders. All considerations peculiarly affecting the artillery must be entirely set aside before the importance of attaining the general object aimed at. It is no good moving from positions from which effective fire can be kept up unless an obvious advantage can be gained, but apparent loss should never stop the advance of a portion, at any rate, directly their fire is masked. It must be remembered that infantry when attacking loses its power of cohesion to a very great extent, and stands in sore need of solid points of support, which can only be afforded by the artillery; and if the attack is brought to a standstill the artillery must be at hand to start it afresh, and to support the wavering troops. Of the effect of this close support there can be no doubt. Von Hœnig describes how, when the 38th Brigade were attacking at Königgrätz, a battery drove to the front at a rapid pace through the skirmishers, and, unlimbering in front of them, opened fire with case at 400 yards. He says, "I have never seen a battery handled with such determination or tactical instinct, and with such brilliant results. It was the initiative, the true initiative of the battery commander that I admire; by which not only were the enemy's battalions severely shaken, but (and this is my point) the confidence of our infantry was raised to the highest pitch of enthusiasm. The loud command 'action front' was heard as far as the troops following in second line, so that the attention of the whole brigade was for a time, so to speak, rivetted on the exploit": and von Moltke tells us how the guns as they crowned the Rotherberg and drove into action beyond the extreme line of Prussian skirmishers were received "with loud cheering by the much distressed infantry." To multiply such instances would be easy; it is sufficient if we remember that field artillery must not shrink from the closest possible ranges if their support is required to carry the infantry attack through. As our Drill Book well puts it, "The greater the difficulties of the infantry, the closer should be the support of the artillery."

As soon as the position is captured every available gun hitherto held back to cover a possible retreat should push forward to shell the retiring enemy. At this moment it is especially necessary to crush by means of a skilful concentration of fire any attempted counter-attack, and the artillery must run all risks to make good the position.

To turn now to more technical matters, and let us take them in the order of the various operations which I have just briefly indicated. First comes the contest with the enemy's artillery. How will this be affected by the fact that the position has been placed in a state of defence? Will the guns be provided with artificial cover? We may, I think, begin by dismissing any idea of their being placed in redoubts, woods, or villages; but will they be in gun pits; and for simplicity let me include epaulements in this term?

A few years ago no doubt you would have unhesitatingly answered *yes;* but I doubt it now. Increased knowledge of the power of field artillery *and of its limits*, gained by practice under as nearly as possible service conditions, has tended, in England at any rate, to greatly disparage the value of gun pits. Year by year such experience has impressed on us that after our own fire, difficulty of ranging for the enemy is our best protection. It has been recognized that gunpits give very poor cover to the gunners, and that it is by killing the gunners and not by disabling the guns that batteries are silenced. Such works may be, in fact, a source of danger. Guns in action afford a very small mark—with a good background one exceedingly difficult to locate. This is, of course, especially so with smokeless powder, but the blast from this is very violent. Put your guns, therefore, into gunpits, cover the new earth with grass or sods, and yet the result will be that, for all your care, their position will be clearly marked by the great cloud of dust that will be thrown up on each discharge.

Generally speaking, then, the best cover for guns is not actual cover from fire—which can scarcely ever be obtained—and not necessarily even cover from view, but such a position that, either from the natural shape of the ground, background, hedges, etc., or from some artificial mask, it is very difficult for the enemy to determine the exact position. But remember, in the case of a mask, that it will have done you poor service if it *masks your own fire* when you wish to turn from the enemy's guns on to their infantry.

To illustrate the influence of ground, I cannot refrain from quoting as an example, hackneyed as it is, a position at Okehampton where a dummy battery has frequently been placed where it is in the clearest possible view at a range of under 3,000 yards, and yet where it has very rarely sustained such loss as would have in any way interfered with its fire. (*Illustrated on the blackboard*).

Lastly, remember that as the best protection for artillery is its own fire, there must not only be a clear field for this, but also there must be no obstacle to all that we understand by fire discipline. Keep brigade divisions together, whether in attack or defence, if you wish to get a decisive effect from artillery fire. Keep your batteries intact *at all costs.* A battery is a shooting machine, and, like most machines, it will not work if you cut it in half. If I may dare to say it in this room, nearly all works on field fortification have missed this point. Three little emplacements on each flank of a village may make a pretty finish to a fortification plate, but such a handling of your artillery will destroy its power.

From what I have said you will see that I am no advocate of entrenchments for guns, either in attack or defence—certainly not in the attack. From what I have heard from officers well qualified to speak, the same ideas appear now to prevail abroad, though a very few years ago this was certainly not so—for instance, the *German Field Artillery Drill*, published in 1892, is a strong advocate of them. For the attack, it appears to me that the use of such entrenchments has all the disadvantages that can be mustered against them, and none of the advantages: above all, the construction of such cover would deprive the attack of their great advantage—the power of surprising the enemy as to their plan.

I think, therefore, that to perform their first duty—the overcoming of the enemy's artillery—the batteries, having been collected under cover, should be brought suddenly and simultaneously into action as rapidly as possible, so as to get over the unlimbering—the most dangerous moment—before the enemy has time to bring his fire to bear. It is important that no previous indication of the position should be given, and that one should be chosen which will develop to the utmost the fire. Against an enemy in a position in a state of defence it is particularly important that it should not be in the proximity of any conspicuous object, as the enemy will have employed his time to much greater advantage than in digging gunpits if he has found the range to such points, and developed means to rapidly concentrate fire on them. Here is an example from the attack on the Forest of Orleans on the 3rd December, 1870:—"The horse artillery formed line and advanced, and at once made a mistake, for it unlimbered at a salient point of the wood. The French knew the exact range, for their first shell burst in the middle of the horseholders of one of the guns."

As regards range, it should be as close as possible as long as:— 1. The guns do not come within long-range fire of the defending infantry. 2. Have not to make a long advance in the open under the fire of the defending artillery.

In most cases no doubt the ground will give little choice, but generally we may take it that the main position will be at a range of 2,500 to 1,500. The advantage of getting as close as possible at once is to avoid wasting fire through difficulty of observation. Remember, time and ammunition are both all valuable to the attack: it is to the interest of the defence to be prodigal of both.

Once in action, the method of the contest with the enemy's artillery is unaffected by the fact that the guns of the defence are entrenched or not; but, of course, in the attack of a prepared position, battery commanders will be especially on their guard against the artifices of masks, etc., and the ranging must be in no wise hurried. As soon as this is completed, fire will be concentrated by brigade divisions on single batteries of the enemy, and in choosing the battery to concentrate on, those which from their position or other reason are most vulnerable should be first selected. Von Schell has well said: "We should not now consider if such a battery from its position will subsequently be able to act with greater effect on the assaulting infantry; this is a matter for afterthought, and should not be considered with reference to where our artillery fire should next be concentrated; it is now a case of artillery against artillery alone, and the question is how we can soonest dispose of that of the enemy. We should, therefore, begin with the easiest task and proceed to cannonade the battery which is least protected. Should we direct our fire at his best protected battery we shall spend more time, obtain less results, and suffer greater loss. We should, therefore, make it a rule always to unite our fire against the least sheltered battery, and to engage last of all the best protected one."

The correct method of obtaining this tactical concentration of fire is one of the chief duties of the artillery brigade division commanders, and great attention has been paid to it in the last two or three years. It used to be assumed that you could disperse your batteries and concentrate your fire! From the lecture-room point of view the idea is a taking one, but directly we came to brigade division practice under service conditions its absurdity was seen. You can have little idea how difficult it is to concentrate the fire of even one brigade division rapidly and accurately when the batteries are in action in line: if they are dispersed it is in most cases almost impossible. Therefore, to get concentrated fire, the batteries must themselves be concentrated.

There is one method of conducting an attack which many officers consider offers great advantages in getting over that terrible zone of fire-swept ground which will, in their opinion, await those who have to attack an enemy who has been able to devote time to developing his defensive strength. That, of course, is what is often spoken of as a night attack—the night march so as to attack at dawn. The *German Field Artillery Drill Book* speaks of thus "bringing the batteries into the selected, and, if possible, prepared fighting position, and commencing the action at dawn"—really much like the arming of siege batteries; and our *Infantry Drill* in its chapter on night operation assumes that the artillery would accompany the force. We know that in the night march to Tel-el-Kebir the artillery was massed in the centre of the army, and in such a position, no doubt, was of great assistance, even during the march, in preserving the line. I have myself seen at cavalry manœuvres three batteries of horse artillery and a whole cavalry division, who were bivouacking in touch with the enemy's outposts, saddle up in the middle of a dark night and get away without the slightest alarm being given; but in both cases it was all soft ground. Where roads have to be followed the circumstances are very different. The noise of artillery moving on roads at night can be heard great distances, and is unmistakable. At the night attack at Aldershot last year, nothing struck me more than the wonderful silence in which that great force of infantry were forming up all round me, and the noise of the artillery some miles away.

Let the artillery in such circumstances be ready to move forward as rapidly as possible directly the rocket goes up, but if you want your attack to be a surprise do not let them move before, unless, indeed, we can somehow muffle the sound, as Napoleon is supposed to have done when crossing the Alps. Experiments in that direction would be interesting. I do not believe many battery commanders know how to do it now.

And now let us suppose that the artillery fight has been so far successful that the order is given to turn the fire on to the point selected for assault. How will the point of attack be placed in a state of defence? Before such an audience I feel naturally reluctant to venture my opinion, but I suppose I cannot go far wrong if I consider the action of the artillery against the following forms of defence:—

1. Earthworks, including both shelter trenches and infantry redoubts.
2. Woods.
3. Villages and buildings generally.
4. Obstacles.

Earthworks.

For many years all field artilleries retained a large proportion of common shell in their equipment, for the avowed purpose of the destruction of earthworks; but as more attention was given to practice people began to notice that for some reason destruction was not at all the result of the fire. The last occasion, probably, of its use in England was at Okehampton in 1893, when a battery fired 60 common at a range of only 1,600 yards at a field work. The practice was excellent, and yet the commandant said in his report:—"The effect on the interior of the casemate was absolutely *nil*, and the damage done to the advanced and protecting bank could in ten minutes have been easily repaired by half a dozen men with shovels"; and remember this was with the most powerful common shell in Europe.

Since then common has been universally abolished and the attempt to destroy earthworks given up. What, then, can field artillery do to them? *They can deny the parapet to the defenders.* However you try to hide earthworks, as long as they command an extensive field, they must remain comparatively easy to "range" on. There are, I know, those who consider that with magazine rifles the distance required to repulse an assault is so short that the infantry position can be retired out of view of the attacking artillery, but the following amendments to the rules for umpires at manœuvres in Germany shows that this deliberate sacrifice of field of fire is not officially approved. It says: "In estimating the importance of shelter trenches, *the clearness of the field of fire*, the strength of the cover, and the visibility of the parapet should be considered"—note the order; and our new infantry drill certainly favours this view. Earthworks have one great advantage as targets: there can be no doubt when they are hit. When firing time shrapnel also, after the ranging has been completed, the bodies of the shells striking and throwing up the loose earth shows plainly whether the accuracy of fire is maintained.

The fire of time shrapnel against them, therefore, can be rapid and accurate, and shell bursting within 50 yards of the crest should prevent any use of the parapet for infantry fire, and should render the reinforcement of the firing line exceedingly difficult; for the bullets of such shell will cover the ground 200 yards in rear of the work.

Doubtless, when the infantry have advanced so close that our fire is masked, the defenders then can man their parapets, and the experience of Plevna shows that with an excellent breechloader and plenty of ammunition, the distance, as I have just said, required to repulse an assault is comparatively short. Yet you must remember that, though the Russians brought up a large number of guns to thoroughly prepare the third assault, the guns were not handled in a way to secure success. In a most interesting paper called *Why did the Russian Artillery Fail at Plevna?* Major May has gone very thoroughly into the question. I will only, however, direct your attention to the following passage :—

"The fire which flows from guns which are intended to bring about a really shattering effect must be kept up as a strong tempest, unremitting, pitiless, and growing in intensity until at the culminating moment it is at its very fiercest.

* * * * * *

"Men become bewildered, dazed, and positively paralyzed under such a visitation ; they lose their coolness, aim badly, and forget the lessons of the practice ground in their nervous haste to reply to the blast which is turned upon them. Now, although the Russians had a vast superiority of guns, and had every facility for thus attacking their opponents, we find no traces of any such handling of their artillery as might make the most of its moral effect."

For the properly arranged fire of artillery against earthworks I claim, then, that the infantry can be kept below the parapet (though they may fire unaimed from there) until the infantry has advanced so close as to mask our fire ; and I believe also that if this fire culminates at that moment the defenders will have suffered so much in nervous energy as to be in no condition to repel the rush of the assault.

In addition, an important duty of the guns is to prevent the reinforcement of the first line. The following passage from a French officer's account of Worth shows how effective this may be :—

"As long as the wood sheltered them from the view of the Prussian artillery, the regiment advanced without difficulty, but the moment the first battalion came into the open the batteries of the V Corps opened a hail of shells, the battalion broke its ranks and the men ran for refuge into the wood. The three battalions in turn did the same. This occurred over and over again while attempting to reinforce the firing line or make counter attacks." These, remember, were not the raw levies of later months, or troops who had been discouraged by previous defeat. At Spicheren too we read that the Prussian batteries "effectually prevented the pushing forward of any reinforcement to the defenders of the trenches on the Rotherberg." I admit that in both these cases the shelter trenches were on the forward crest, so that the conditions were favourable to the artillery, but *Infantry Drill*, 1896, particularly states that it is just "when the convexity of the slopes renders it necessary to place the firing line in advance of the crest line" that "field entrenchments will be found especially useful."

Woods.

Against woods, unfortunately, we have no recent experience of the effect of artillery. I believe that with the present extremely low value of timber such an experiment might be conducted at small cost—perhaps there may be a chance on Salisbury Plain—but as it is we must go for our experience to 1870–71. Fortunately we have a particularly full account from Prince Kraft of the shelling of a wood at the Battle of Sedan, which I will read to you, as it was conducted on the principles that would be followed by English artillery if we had such a task to perform to-morrow:—

"It was perfectly clear that by taking the Bois de la Garenne we should complete the entire defeat of the army of the enemy; it was therefore determined to carry this wood. The 1st Division of the Infantry of the Guard formed up for the assault. But since masses of infantry which had composed two of the enemy's beaten corps were crowded together in this wood, it was necessary to begin by preparing the attack. With this object I divided the long edge of the forest which extended before us into sections, and I assigned one section to each of my batteries. The first gun of each of these units was to fire at the very edge of the wood, and each of the following guns was to fire in the same direction, but was to give 100 paces more elevation than the gun on its right. In this manner the edge of the forest and the forest itself to a depth of 500 paces would be covered with a hail of shells. The splinters would carry yet farther. But as soon as any portion of the enemy's troops should appear outside of the forest, then immediately all our guns were to direct their fire on it and destroy it.

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"All at once a line of Prussian cavalry coming from the direction of Illy approached the northern point of the wood at the spot where the Cavalry stands. A thick mass of infantry with red trousers rushed out of the forest against them, and fired on them from the quarry by the Cavalry. It was an exciting moment. Will our guns, which are laid exactly on this point, be able to throw back the enemy's infantry, and prevent it from destroying our cavalry, upon which they have opened fire?

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"At the same instant the greater part of the guns opened their rapid fire; a cloud of shells, which burst as they touched the ground, enveloped the enemy in a thick smoke, and they very soon fell back into the forest.

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"The batteries were once more pointed at the forest, and continued to bombard it. At length the moment to attack was come; orders had been given that a salvo fired by all our guns should serve as the signal to carry it out. We fired the salvo at 2.30 p.m. precisely, as had been arranged, and our infantry, starting from Gavonne, began to climb the hill.

"We were in a state of feverish expectation; every eye was fixed on the forest; we asked ourselves if the capture of the edge of the wood would cost as many lives as had that of Saint Privat. But this time the resistance met with was almost *nil*. At most points the French, utterly discouraged, advanced to meet our troops crying: 'Mercy, mercy, we can do nothing; we are crushed by the fire of your artillery.' Only in the interior of the forest did they try to fight at certain points, and even there the resistance was not stubborn."

You will very probably say that the edges of woods would not be occupied, but shelter trenches outside them. In such a case what I have just said as to the attack of shelter trenches would apply, but I admit that the dark background of the wood might make the trenches hard to observe and, therefore, to range on. I think that very possibly a simple firing line lying down in heather some hundred yards or so in front of a wood might deceive us completely, and the fire be all directed on the edge of the wood, but then care must be taken that the position is not "given away" by supports, etc., moving up to the firing line. I remember a battery in such a position at a field day completely deceiving a superior force of the attacking artillery, who could not localize it at all until its position was discovered by a staff officer being seen to ride up to it.

In the case of a defensive line being in rear of a wood, the difficulty of the artillery is enormous. To bring guns through a wood and into action against troops pouring a heavy fire on its further edge would in many cases be impossible. Some Bavarian batteries tried it on the extreme German right at Worth and failed, though the guns of the XI Corps were so brought up on the left of the same battle with the greatest success. There is no doubt, I think, that where the attacking infantry are fighting their way through a wood some batteries should be sent forward by any available way to support them when they have reached the further edge. There is a great chance that, if skilfully handled, they may be able, by utilizing any fold in the ground, to get into action before the attention of the defenders is turned upon them. Once in action, artillery is no more vulnerable, and in many ways less so, than infantry.

Villages.

As regards villages and buildings generally, there is rather a general idea that with only shrapnel field guns will not be as effective as they used to be. It is well that it should be thoroughly understood that it has been proved by experiment that shrapnel will penetrate with ease any ordinary wall and burst most effectively at the other side. They may possibly not knock things about quite as much as common did—they will certainly not have so great an incendiary effect (though this is by no means always a disadvantage)—but they will have quite as great and probably a greater man-killing effect. To the power of both there is the same limit: bursting as they do in passing through the first wall, neither the splinters of common nor the bullets of shrapnel will pass through a second. Until, therefore, the outside wall is so demolished that the shell strike direct on to the second wall, troops behind the latter are safe. To bring about such a demolition of the outer wall so great an expenditure of ammunition would be required that it is scarcely likely to take place, unless, indeed, in the case of a solitary building obstinately held, on to which the fire of a great number of guns can be concentrated. There is one point about the attack of buildings that must not be lost sight of. Owing to the fact that the laying is extremely easy, and that *percussion* shrapnel are used, the fire of the attacking artillery can be continued with safety until the assaulting column are much closer than would be generally safe. The wonderful effect of the fire of the siege guns at S. Sebastian over the heads of the stormers baffled at the foot of the wall may be familiar to students of the Peninsular War. Remember, too, Wyndham's message from the Redan. He says: "I accordingly crossed the ditch, and young Swire having returned, I sent him back immediately *to desire that our batteries would keep up a heavy fire upon the Redan no matter whether they hit us or not.*"

But, as in the case of woods, you may say the defenders of a village will not be placed in the houses, but will occupy garden fences, etc., in the outskirts: they would then be attacked as shelter trenches. In many cases, no doubt, the irregular lines would present difficulties to us which would necessitate our employing the same method of fire as I have described for searching a wood. By this means the outskirts of the village for one or two hundred yards depth would be kept under a fire of time shrapnel; but, of course, to be effective, this fire must be concentrated, only a very small breadth being told off to each battery, as for instance at Noisseville, S. Marie aux Chênes, and previous to the final assault of S. Privat.

There is another use of field artillery in the attack of villages. It must always be exceptional, and probably in every case the loss will be great, but you cannot make omelettes without breaking eggs. When necessary, guns may have to be pushed into the interior for some specific purpose. Instances are not wanting. At Bazeilles the Bavarians brought up two guns to within 70 yards of a large house occupied by the French from which they had been previously repulsed, and thus forced the French to abandon it. The same guns were dragged by hand through a side street to attack another house, but on this occasion they had no success, but were themselves driven back by the French rifle fire.

Perhaps the following is a more legitimate use of the artillery of the attack. It is especially noticeable in the case of a village, because there is probably no operation in war in which the assaulting troops are more broken up and generally demoralized, and in consequence more at the mercy of a counter attack. The duty of the artillery is to save the assaulting troops from this danger, and give them time to recover. I cannot give you a better explanation of such use than by reading you the account of the action of the German artillery at the assault of Elsasshausen. After the storming of the village of Elsasshausen, while the infantry were still in the confusion inevitable after such a struggle, the French delivered a strong counter attack with their reserves.

"With no intact supports, almost without leaders, loosened and exhausted by the long and violent struggle, these troops were unable to withstand the charge of the French masses, and sought shelter in the Niederwald." At this moment one of the horse batteries was moving round the village to find a position to the west of it. They were involved in the crowd, but fortunately a moment's pause gave them an opportunity of extricating themselves, and one of the field batteries coming up at the same time, the two batteries halted and came into action with case against the advancing enemy. At the same time the other horse battery on the other side of the village had reached it just as the head of the French column appeared on the heights to the north, scarcely 600 yards away. "Although at this time the Prussian infantry further to the left was retreating, the horse artillery battery unlimbered, and whilst other batteries of the 11th Corps came into action eastward of Elsasshausen, this battery, after a few rounds of shell, received the advancing foe with case, until the latter found himself compelled to retire when only 150 paces distant."

To take another instance where, indeed, the counter attack was never delivered. The first thing the Germans did after S. Privat had at length been carried at such enormous loss of life was to form a huge battery of 240 guns, which were in action right and left of the village all through the night of the 18th August.

Obstacles.

I must fairly confess that against obstacles the fire of field artillery is practically useless. Certainly I should never think of wasting ammunition on them.

High-Explosive Shells.

In everything I have said so far I have imagined ordinary field guns firing shrapnel, and I have not disguised from you that in many ways they are very ineffective against field defences—especially against troops behind earthworks *as long as they remain behind their works*. Plevna, of course, brought this fact into especial prominence, and since then attention has been paid to the subject, and in all countries two solutions have been proposed: high-explosive shells for field guns; and field howitzers.

To take the first. I suppose that since the French mitrailleuses, which were supposed to be going to do such wonders in 1870, no military invention has had such an amount of rubbish written about it. High-explosive shells were to blow everything out of the field. Here is an account from a German paper professing to be technical.

"A NEW GERMAN FIELD GUN.—It is stated that a new field gun has been produced for the German army, which possesses several advantages over the weapons at present possessed by any of the European Powers. Now four different kinds of projectile are used, but the new gun would only have one—explosive shells. These are substantial advantages; but a far greater remains in its destructiveness, its powers in that direction being prodigious. The splinters of a shell have been estimated to cover an area of 30 or 40 yards, but those of projectiles discharged from the new weapon cover a surface ten times as great, so that a regiment would in a few minutes be swept away by a single gun." *Prodigious* is certainly the right word; but if the German army expect their artillery to destroy regiments in this wholesale way, I am afraid they will be grievously disappointed.

An English writer, who has followed *very far* behind the Battle of Dorking, describes how a single high-explosive shell from a French field battery falling in the courtyard of the Royal Academy levelled Burlington House. If it had broken the windows it would have been the utmost it would have done.

Putting aside such sensational accounts written for the gallery, let us see what is really known about these high explosives. The only nations who have actually adopted them are the French and Germans, and perhaps the Austrians—who have all from 15 to 25 rounds per gun. They do not propose to use these shells under ordinary circumstances against troops in the open, where it is now admitted that they cannot compare with shrapnel, but to search out earthworks and prevent the defenders sitting in safety with their backs against the parapet. For this purpose the supposed all round effect of the very violent explosion is to be made use of. There are two methods by which it has been proposed to do this. In the first, percussion fuzes are used, and the fire is so directed that the shell may strike the superior slope and burst almost immediately after graze. In the second, the range to the crest having been found, the elevation is slightly increased, and fire continued with time fuzes set to burst immediately above the crest, or if anything a little beyond it.

Either of these would require an extraordinary accuracy of fire quite beyond the gun or the fuze; but, gentlemen, as far as I have been able to learn from experiments, which have been directed to this very point—even if you succeed in bursting your shell exactly over the crest, the effect is almost *nil*. Theoretically the idea is excellent, practically it doesn't come off!

Against houses also, although high-explosive shells, owing to the violence of their blast, do more damage to the walls than shrapnel (making holes three or four feet square in an ordinary brick wall), they do not at all get over the fact that troops behind a second wall are safe. For the actual breaching of earthworks it is probable that our old common shell—useless as that was—was as good or better than a high-explosive shell.

I think, gentlemen, that you need not therefore be alarmed about any wonderful effect from the high-explosive shell of field *guns* against your defences. When we turn to field howitzers it is another matter.

FIELD HOWITZERS.

While France, Germany and Austria have sought for the solution of the problem in providing their field guns with high-explosive shells, Switzerland and Russia took the lead in creating field howitzer batteries. In Switzerland these are organized with guns of position into a regular position artillery for defensive work; in Russia they are undoubtedly intended for the attack of positions. By the end of last year Russia would have had 26 (six guns) howitzer batteries, separate from corps and divisional artillery, while in 1890 there were only eight such batteries. This great increase in the last six years is very striking. Turkey in the last two or three years has raised 12 batteries of field howitzers to be attached to the 2nd and 3rd Corps, which I think are the ones being mobilized at present, and Bulgaria has a howitzer battery with each division, so that if war does break out in the East we are likely to see this new weapon brought prominently to notice. We in England, as you probably know, have two 4-gun batteries of similar howitzers.

So far other nations have not established actual field howitzer batteries; but nearly all have experimented with them, and it is probable that those who have not adopted them have been influenced not so much by the idea that they will not be required, but by the belief that better value will be obtained by temporarily horsing the lighter units of the siege train and giving them a certain amount of field training Germany and Austria have taken the lead in this.

There is, I think, then, no doubt that in the attack of a regularly prepared defensive position the fire of the field artillery proper will be supplemented by that of high-angle pieces firing heavy shells. For our present purposes, the effect on the defence, it does not much matter whether these are classed as field or light siege. You must remember that what are called *field* howitzers by no means possess the mobility of field guns—for instance, in our own equipment the gunners are not mounted.

How then will they be used? To answer this we must think of the effect of their shell. First of all the high explosive is a very different article in a 50 or 60lb. shell to what it is in a 15lb. one. There is no doubt that high-explosive shells from howitzers will have enormous effect if judiciously used.

Against troops in the open, high-explosive shells from guns or howitzers have very little effect. A shell falling in the middle of a column *might* have greater effect than a good shrapnel; but columns are rare targets, and the accuracy required to get an effective shell is much greater than with shrapnel. The great disadvantage of high-explosive shells against troops is their small *forward* effect, the angle of opening being as much as 140°.

High-explosive shells from howitzers with percussion fuze would, however, be of great value against troops behind cover, which cannot be searched by shrapnel. They will also demolish field casemates and all overhead cover.

Against wire entanglements high-explosive shells, even from howitzers, have little effect, for though they clear a considerable space (as much as 12 feet square) a crater four feet deep is left in the space with the wire coiling all round. As an obstacle, therefore, the entanglement is as good as ever.

Against abattis high-explosive shells from howitzers are, however, effective. A shell detonating on the abattis may clear a passage 12 feet wide through a row *without making a crater*.

If such is their power and its limitations, gentlemen, how shall we use them?

At first, of course, the advocates of the new thing wished to do everything with it, but I think that the opinion is gaining ground that their proper use is for shelling the point of attack. Brought up during the preliminary engagement, they will be placed in a position as soon as the point of attack is decided on, and will bring a concentrated fire to bear upon it under which I cannot imagine a field redoubt, for instance, remaining tenable. The great weight of their ammunition, their comparative immobility, and the probably poor effect of their fire as compared with that of the ordinary field guns against troops in the open (especially when moving), seems to me to point to the desirability of not attempting to use them in line with the field artillery in the battlefield.

But, gentlemen, I can only speak vaguely, for really very little is known about their powers. No practice has been carried out with them under service conditions as yet. This year at Okehampton a field howitzer battery will not only have to fire at field defences, but there will also be a trial between it and an ordinary field battery, under conditions arranged as far as possible to represent the actual work probably required of a battery in a day's action. This will afford us valuable information on the accuracy of fire to be expected from a howitzer battery under service conditions, and of its mobility in difficult ground—both most important subjects about which we now know little or nothing.

In conclusion, gentlemen, I can only say that I have endeavoured to show you not only our strength, but our weaknesses, because I believe that though "confidence in oneself and a feeling of the certainty of victory are the essentials of great successes, they must be based on realities. Unless this is the case there is considerable danger that a check at the decisive moment may transform this confidence into an opposite feeling."

PAPER IV.

WIND PRESSURE ON ENGINEERING STRUCTURES.

BY PROFESSOR W. C. UNWIN, F.R.S., M.I.C.E.

THE action of wind storms on structures is important enough it is true, for the engineer has to erect bridges and other structures of great height and exposing large surface, and on these the lateral pressure and overturning action due to wind may be far too large to be neglected in estimating the straining action to be provided for. But it is a subject on which it is not very satisfactory to have to express opinions, at any rate in a detailed way. First, it is a subject about which there has been much controversy, and a good deal of feeling has been aroused; and second, the data on which opinions must be based are not by everyone accepted or interpreted in the same way. After the Tay Bridge disaster, which without question was due to the action of a wind storm, the Board of Trade adopted Rules for the allowance for wind pressure in designing structures subject to their control, which in the opinion of many practical engineers are absurdly stringent and impose unnecessary obligations in the construction of works, especially railway bridges.

It would be pleasant if one could at once say that the Board of Trade Rules are necessary and rational, or if one could say with the objectors that they are unnecessary and should be abolished. But neither course is at present possible, and the reason is that the magnitude of the action of the wind in different cases is still somewhat uncertain and obscure. The action of the wind in straining structures is in any case important only at rare intervals of time, and depends on the direction as well as on the velocity and force of the wind storm. The maximum pressure of the wind even on bodies of simple form in different conditions of exposure is imperfectly ascertained, and as to the maximum pressure on complex engineering structures in any given position, those who have thought most on the subject will be least likely to be dogmatic or to commit themselves to very definite estimates. It is not subject to dispute that in one set of conditions the wind has force enough to cut a pathway across a country, mowing down trees and levelling buildings with apparently resistless energy. Or that, in other conditions not obviously different, there have stood unharmed and exposed to every wind for long periods chimney stacks and other tall buildings known to be of very moderate powers of resistance to a lateral force.

Long ago Smeaton and Rouse and others experimented on wind velocity and wind pressure. But it was rather with reference to the utilization of wind power in mills, and to the question of stability of ships and the resistance of projectiles that these older inquiries were directed. For thirty or forty years meteorologists have measured wind velocity and wind pressure, but their records were little noticed by engineers. A wind storm in 1856 bent the great chimney at the St. Rollox Works at Glasgow, and this directed Rankine's attention to the effect of wind pressure on structures, and he made interesting calculations of the stability of such structures, given in his *Applied Mechanics.* About the same time Nordling, the French engineer, made calculations of the wind pressure in designing lofty bridge piers. In 1868 I had to deliver at Chatham some lectures on bridges and roofs. I believe, that then for the first time attention was called to the necessity of considering wind pressure on large roofs as one of the most serious of the straining actions to be resisted. It was then first pointed out that wind pressure is a force normal to the roof surface, producing large straining action from its unsymmetrical distribution. To estimate its amount some experiments on small plane surfaces by Hutton were used, and Hutton's formula was modified to obtain the normal pressure. Hutton had measured the effort in the direction of motion only, which is one component of the normal pressure. Shortly afterwards my treatment of wind pressure was challenged, and I wrote a memorandum which was printed at Chatham, which omits some things no doubt, but which contains nothing I should even now dissent from. I had not been challenged as to the magnitude of wind pressure on planes normal to the wind, as to which information was very scanty at that time. But I was challenged as to the interpretation of Hutton's results, and on that point I had a satisfactory answer. Some experiments made for the Aeronautical Society just at that time in which two rectangular components of the wind pressure were separately measured, were in complete agreement with my modification of Hutton's formula. Then, in 1879, came the terrible Tay Bridge disaster, due undoubtedly to the insufficient strength of the bridge to resist wind pressure. Not long after, a large mill building was blown down at Glasgow. Since then engineers have paid a good deal of attention to wind action on structures. Very interesting experiments were carried out by Sir Benjamin Baker at the Forth Bridge, and more recently Sir Wolfe Barry has obtained results as to the action of the wind on the Tower Bridge, which are not yet published. Allowances for wind pressure are now made by engineers in accordance with rules laid down by the Board of Trade. Very possibly these allowances are excessive, at any rate in ordinary cases, and are only strictly required in cases of exceptionally severe exposure at considerable elevation from the ground. The difficulty is to apply any general rules to so fickle and variable an action, which shall secure safety in extreme cases, and which shall not in the majority of cases involve an excessive margin of security and consequently a waste of material.

Origin and Character of Wind Storms.

A common cause of wind is the vertical ascent of a column of air heated by contact with the ground, inducing a horizontal flow to replace the rising air. The alternate daily land and sea breeze near coasts is due to the land being warmer during the day, the replacing current then flowing landwards; and the sea being warmer at night, the replacing current then flowing seawards. Winds due to temperature differences of this kind are comparatively gentle. Storm winds have generally a different character. They are rotating eddies in the air which are generated between two oppositely flowing wind currents not themselves of a violent character. Once put in motion, the energy of such an eddy accumulates, and the distribution of the energy is a purely mechanical problem.

Conditions of dynamical stability involve this, that the pressure diminishes and the velocity increases from the circumference to the centre of the eddy. *Fig.* 1, a diagram of the St. Louis storm of 1896, shows that the isobars form closed curves round the storm centre, the barometric pressure diminishing from 30 inches at the outside to 29·4 inches at the centre. On the other hand, the velocity and violence of the wind increase towards the centre

The directions of the arrows show that the wind moved neither radially nor exactly round the storm centre, but spirally towards the centre. When a cyclonic storm of this kind is observed over land and necessarily near the ground, local topographical features cause considerable irregularities in the wind's direction. Over the sea the rotating character of a wind storm is more easily observed. *Fig.* 2, which is perhaps a little more theoretical, is a diagram of a cyclonic storm plotted from observations taken at sea.

A rotating eddy or storm of this kind is not fixed in position. Its centre travels along a track generally, in the northern hemisphere, eastwards or north eastwards. At any given place, as the wind storm passes, the wind veers round contrary to the hands of a watch. The storm centre may travel at 15 to 20 miles an hour, but the wind velocity near the centre of the storm may be 80 or 100, or more miles per hour. The area of a storm is extremely variable. It may be 600 or 1,200 miles in diameter. In other cases the diameter may be so small that the width of the track over which the wind is violent enough to cause destruction may be only 60 to 1,000 feet. Some small whirlwinds cut down the trees in a forest along a track as narrow as a lane, leaving the trees on each side undamaged.

Wind Pressures Observed at Meterological Stations.

Wind pressures are directly measured on anemometers consisting of a thin vertical plate exposed normally to the wind. It is no doubt rare in most positions for the wind pressure on such a plate to exceed 30 lbs. on the square foot. But, forty years ago, Rankine gave 55 lbs. per square foot as the highest recorded pressure in this country, and the data collected by the Board of Trade Committee, in the Tay Bridge inquiry, show that Rankine's statement was not an exaggerated one. It appeared in the inquiry that on pressure plate anemometers at Birmingham, pressures of 20 to 27 lbs. per square foot had been recorded ; at Edinburgh, pressures of 20 to

25 lbs. per square foot; at Glasgow, pressures of 30 to 47 lbs. per square foot; at Greenwich, pressures of 30 to 42 lbs. per square foot; and lastly at the Bidston Observatory, Liverpool, pressures of 50 to 80 lbs. per square foot had been registered. The last case was so remarkable, that special inquiry was made by the Committee as to whether there was any error in the anemometer at Bidston, or local cause of the high pressures observed. The anemometer is 56 feet above the ground, and 251 feet above sea level. The Observatory is on a range of hills rising abruptly from the sea level. The exposure of the anemometer is complete and severe, but there appeared to the Committee to be no reason to doubt the accuracy of the records. Tornadoes in America have been estimated to exert a pressure of 84 to 100 lbs. per square foot. The destruction of the upper portion of the masonry approach to the St. Louis Bridge, a tall chimney, a grain elevator and other buildings in the tornado of 1896, led Baier to the conclusion that the wind pressure must have ranged from 45 to 90 lbs. per square foot.

Observations on Wind Velocity at Meteorological Stations.

At many stations only the wind velocity is observed. From this the wind pressure can be calculated by a fairly well-established formula. Smeaton first gave as the relation between the wind pressure p in lbs. per square foot on a completely exposed plate normal to a wind travelling at V miles per hour.

$$p = 0{\cdot}005\ V^2.$$

Later experiments seem to show that the constant in this formula is possibly somewhat too high, and Mr. Dines has given the expression

$$p = 0{\cdot}0035\ V^2.$$

However, in applying these expressions to records of velocity anemometers, we are met with a difficulty. The anemometer records give only the average velocity over a more or less considerable period of time. The Board of Trade Committee got over this difficulty by comparing for a series of years the pressure plate and velocity records taken simultaneously at Bidston Observatory. They found that for periods of great wind storms, if V_m is the mean velocity during an hour, then the highest pressure shown by the pressure plate anemometer during the hour would be approximately

$$p = 0{\cdot}01 \ V_m^2.$$

This indicates, speaking roughly, that over a period of an hour at the height of a storm the maximum pressure is only two to three times the mean pressure, or more strictly the pressure due to the mean velocity during the hour. If we adopt this rule then there are many stations at which only velocity observations are taken, the records of which confirm the high pressures shown by the pressure plate anemometers. Thus, the records at Aberdeen show a wind travel of 69 miles in an hour, which by the Committee's rule would correspond to a maximum pressure of 48 lbs. per square foot. At Falmouth a wind travel of 71 miles an hour has been recorded, corresponding to a pressure of 50 lbs. per square foot. At Holyhead a travel of 80 miles an hour, corresponding to 64 lbs. per square foot. The velocity observations from four Continental stations give somewhat smaller maximum pressures, and those from one station in India a maximum pressure of 40 lbs. per square foot.

But the velocity observations are important in another way besides affording a general confirmation of the pressure plate results. It is sometimes alleged that the high pressure plate records are merely momentary, and that they are either due to inertia effects of the instrument or to sudden gusts of almost momentary duration. Hence it is argued that the general wind pressure over any appreciable time is much smaller than would be supposed from observations with pressure plates. But the velocity records very distinctly prove that the mean pressure during so long a period as an hour is roughly as high as half the maximum pressure shown by a pressure plate in the same period. It is impossible, therefore, to attribute the pressure plate pressures either to errors due to the inertia of the instrument or to gusts of short duration. The velocity anemometer is practically free from inertia errors, and the ratio of maximum to mean is not consistent with the supposition that gusts during which the pressure is excessive are of very short duration.

Confirmation of Anemometer Results by Facts Observed in Storms.

When a body of known dimensions and weight is overturned it is possible to calculate the overturning force. Thus it may be shown that to overturn an ordinary railway carriage, a pressure of about

30 to 35 lbs. per square foot, distributed over the area of the side of the carriage, is necessary. Numerous cases have been recorded of railway carriages overturned in wind storms.

Thus Mr. Seyrig has described the overturning of five carriages of a passenger train at Salces, in France, on February 27th, 1860.

A brake-van, which it was estimated would require 50 lbs. pressure per square foot to cause overturning, was left standing. The same day five waggons in a freight train were overturned at Rivesaltes, and three others thrown off the track. Here a pressure of at least 27 lbs. per square foot was required to explain the overturning. On the same railway in 1867 a passenger train was almost completely overturned. It was estimated that pressures of 25 to 30 lbs. per square foot were required for different carriages.

On Shap Incline, between Preston and Carlisle, in 1855, three cattle waggons and three sheep vans were blown over. In 1867 a brake-van and post-office tender were blown over between Chester and Holyhead. In 1864 carriages in two trains on the Eastern Bengal railway were overturned by wind. In 1880, on the South Indian railway, an empty covered goods van was blown over while standing in a siding.

In 1871, if the story can be credited, at East St. Louis, in the United States, a locomotive was overturned. It was believed that wind was the cause, and that the pressure must have been 93 lbs. per square foot.

In the United States in 1866, ten spans (250 feet each) of a bridge were blown over, the estimated wind force required being 27 lbs. per square foot. In 1870 two spans of a bridge at Decatur were blown over, and in 1880 one 150-foot span of another bridge at Meredoçia.

There are other disasters which prove very great wind force, though it is less approximately calculable. Mr. Symons has put on record the case of a country waggon in Wiltshire which was lifted bodily by the wind, carried sideways, and dropped without overturning. In 1868 two continuous spans of 116 feet of a bridge in Mauritius were blown from their piers. In a hurricane in Mauritius in 1818 a theatre 82 feet by 53 feet by 34 feet high was shifted five feet on its foundations.

The Marshfield tornado in the United States in 1880 has been described by Mr. Shaler Smith. This was one of the cyclones of small diameter which cut a track only 1,800 feet wide. At one point a five-roomed brick house was levelled with the ground, and a piano which had been in the house was carried 270 feet. A tornado of still smaller dimensions occurred at St. Charles, near Boston, in 1877. It cut a track only 60 feet wide, and within this track houses and trees were completely swept away.

Description of the St. Charles Tornado in 1877.

I select from a description by Mr. C. C. Davis, an eye-witness, some striking facts illustrating the violence of the comparatively narrow tornadoes which sometimes occur, and which almost cut a clear track along their path. The wind storm was preceded by a hail storm, some of the hailstones being of enormous size. Suddenly the lurid brown of a cyclone column appeared in the S.W., about three miles from the city. The cloudy column moved eastward at first, and then along the river bank, its coming presaged by a deep toned humming roar. In appearance it was a brown murky vertical column, largest at its junction with the storm cloud above—never more than 400 feet in diameter—reaching sometimes to the earth, where it destroyed all that it touched, occasionally receding upwards, and passing harmlessly over intervening spaces. The central vortex reached the spire of the German church, a twist, a crash, the spire went spinning upwards, preserving its vertical position till near the top of its flight, when it was suddenly reversed, and came down point foremost. This vortex also touched the jail, the roof of which, together with the whole upper storey, was twisted off, and to this hour the roof has not been found. From this point the scene beggars all description. The total destruction of everything grasped by the tornado can be compared only to the wide-spread ruin produced by the explosion of a powder magazine. The streets were filled with heavy timbers reduced to splinters. Near the vortex houses were destroyed by twisting and bursting. On the circumference of the storm houses were crushed and overturned. It crossed a bridge without destroying it, but destroyed some large trees beyond, and lifted some of the water 200 feet. Half an hour after the storm was over and the sun shining.

If you are disposed to think that such violent wind action is confined to the other side of the Atlantic, where most things are on a large scale, let me quote a few facts from an account of a wind storm in Paris this year, on September 10th. The cyclone struck the city at a quarter to three, and lasted a very short time. From the Quai St. Michel to the Pont Neuf, and for some way beyond, every tree was uprooted. Several barges were sunk. On the Pont au Change an omnibus was overturned, several carriages were upset, and shops had their fronts blown in. At the Palaîs de Justice not a pane was left in the windows, and part of the roof was blown off. At the Sainte Chapelle, which was undergoing repairs, part of the scaffolding fell with a crash. A dozen persons were blown into the Seine. Nine journalists on the staff of *la France* were blown down, and one of them killed.

Cleopatra's Needle.

An engineer often has to consider the case of isolated structures of great height, subjected to wind pressure. When Cleopatra's Needle was erected on the Thames Embankment, a good deal of discussion was raised as to the possibility of its being overturned by the wind. A letter with respect to this, evidently by an engineer of considerable knowledge, appeared in *Nature*. The calculations in that letter rested on the assumption that the rounded base of the obelisk had a diameter of only five feet, and neglected the extension of base, afterwards secured by the bronze cap surrounding the base. Nevertheless they are interesting. The writer concludes that the obelisk, standing as it did at first on its damaged base, and cemented to the foundation, would resist a wind pressure of 21 lbs. per square foot, without any tendency to accident. If subjected at comparatively long intervals to a pressure of 40 to 50 lbs. per square foot it would probably stand for a long period, until the fatigue of the cement under the base caused its rupture. If with such pressures the period of the gusts timed with the natural period of oscillation of the obelisk, it would probably be overturned at once. Lastly, if the wind pressure ever reached 80 lbs. per square foot, it was probable that the survivors amongst inhabitants of the neighbourhood would not find it *in situ* when they had time to go and look for it.

The Accident to the Tay Bridge.

The original Tay Bridge, neglecting the shore spans, had twelve spans of 145 feet, and thirteen spans, generally termed the central spans, of 245 feet in the clear. The bridge was opened for traffic in May, 1878, but on December 28th, 1879, there occurred the great disaster, in which, during a violent gale, the thirteen large central spans over which a train was passing at the time were overturned and fell into the river. The portion of the bridge which fell consisted of three sets of continuous girders, covering five, four, and four spans respectively. Each set of continuous girders rested on roller beds on its piers, except at one pier, to which it was fixed. The piers were lofty skeleton iron piers, carrying the girders at 88 feet above H.W.S. tides. The girders turned over and fell into the river on their sides. The train was found in the fourth and fifth spans from the south end. The Westinghouse brake had not been put on, and the steam valve of the engine was full open, the inference being that those in the train had no warning of the disaster. Some of the vertical columns of the iron piers had been found cracked some months before the disaster, and precautions had been taken to strengthen these piers. The appearance of the fallen girders pointed to the likelihood that the lofty piers had given way near their base, and that the bridge had overturned about the bases of the piers. The general conclusion was that the iron piers, with their cross bracing and fastenings, though strong enough for the vertical load, were too weak to resist the lateral action of heavy gales of wind.

The Court of Inquiry appended to their verdict the remarkable statement that at that time there was no requirement issued by the Board of Trade respecting wind pressure, and there did not then appear to be any understood rule in the engineering profession regarding wind pressure in railway structures.

Relation of Wind Pressure and Wind Velocity.

The engineer is chiefly interested in the relation of wind pressure and wind velocity, and in the relation of the pressure on surfaces normal to the wind to that on surfaces oblique to the wind.

Newton first pointed out that when a current of fluid strikes a plane normally, the greatest intensity of pressure is equal to the weight of a column of the fluid of unit area and of a height equal to the velocity height. Let A be the area of a plane in a current of velocity v, and let G be the weight of a cubic unit of the fluid. Then the direct or front pressure is given by the relation

$$P = G\,A\,\frac{v^2}{2\,g}.$$

If we put G for air = 0·0807 lbs. per cubic foot, and substitute V = 1 466v in miles per hour, for v in feet per second, then the normal pressure in lbs. per square foot on the surface directly struck is

$$p = 0{\cdot}0027\ V^2.$$

For a body of any form Newton pointed out that the whole resultant pressure would be

$$P = 0{\cdot}0027\ AV^2 \times K,$$

where A is the projection of the body normal to the wind, and K is a constant depending on the form of the body. Experiment shows that even in the case of a thin plane exposed normally to the wind there is in addition to the direct front pressure a negative back pressure, so that for this case K = about 1·7. Then for a thin plate of this kind, such as an anemometer plate—

$$P = 0{\cdot}0046\ AV^2,$$

a result which differs little from Smeaton's experimental result given above. Mr. Dines found a somewhat smaller value for the constant, but his experiments were made with a rotating plate, and it is possible that this affected his results.

The following table gives the resultant pressure of the wind in lbs. per square foot on planes struck normally in conditions of exposure, in which the negative back pressure as well as the direct front pressure are developed :—

V. Miles per Hour.	P. Lbs. per Square Foot.	
	Smeaton.	Dines.
25	3·1	2·2
50	12·5	8·8
75	28·1	19·7
100	50·0	35·0
150	112·5	78·8

It will be seen that it is only when the wind velocity is equal to or greater than 50 miles an hour that the wind pressure is an important loading force on structures.

Fig. 3 shows by a curve the increase of wind pressure with wind velocity, and its division into a + or front pressure, and a – or vacuum pressure behind the plane. The figure relates strictly to the case of a thin plane normal to the wind, and with freedom from interference with the development of the negative pressure behind the plane.

Composition of the Resultant Wind Force on a Normal Plane.

It is important that the total wind pressure as generally measured is made up of a direct front pressure and negative back pressure. The vacuum behind the plane is due to the convergence of the wind stream round the edges of the plane. Experiment shows that of the whole pressure on small planes about 55 to 60 per cent. is positive front pressure, and 45 to 40 per cent. negative back pressure.

Pressure plate anemometers register the sum of the front and back pressure. In many cases, however, the convergence of the wind at the back of a structure is interfered with or prevented. The wall of a building, for instance, carries the front pressure only. Then we ought to take the pressure due to any given wind velocity as only $\frac{6}{10}$ lbs. of the anemometer pressure. A good deal of confusion has probably arisen from not distinguishing cases where a vacuum at the back is formed and cases where no region of low pressure at the back can exist.

Variation of Wind Velocity from the Ground Upwards.

Numerous experiments show, as might be expected, that the wind velocity, and therefore the wind pressure also, is greater the greater the height from the ground. Perhaps the most instructive experiments are those made by Mr. Thomas Stevenson in 1878. Six velocity anemometers were fixed on a vertical pole 50 feet in height, in a large and level field, and observations were taken at various dates when strong winds were blowing For a height of 15 feet from the ground the velocities were low and irregular, even when the wind was strongest. For heights above 20 feet the velocities increased in a very regular way with increase of elevation. If the velocities at each height are plotted horizontally, we get the black velocity curve in *Fig.* 4. For all the observations, with different winds, the vertical velocity curve at heights above 20 feet agreed well with a parabola having its vertex 72 feet below the ground level. If V and v are velocities at heights H and h—

$$V = v\sqrt{\frac{H+72}{h+72}}.$$

Hence if P and p are the pressures at those heights—

$$P = p\,\frac{H+72}{h+72}.$$

Suppose the pressure at 50 feet is 30 lbs. per square foot, then by Mr. Stevenson's law, assuming that it may be extended to great heights :—

Height above Ground in Feet.	Wind Pressure, Lbs. per Square Foot.
50	30
100	42
200	66
300	91

These increments of pressure are large. The practical bearing of the results is this :—(1). Near the ground, even in open country, we must not expect to find great wind pressures. (2). The variations of pressure with height are sufficient to explain some of the discordances of records at meteorological stations. (3). It is on lofty structures that the necessity of attending to wind pressure is most urgent.

Let me specially call your attention to the great irregularity of the velocity curve, and the lowness of the velocities near the ground, even in a position selected, so that there should be as little obstruction to the free action of the wind as possible. *A fortiori*, the pressures which vary as the squares of the velocities are small near the ground. A good many of the facts as to the endurance of chimneys and walls and other structures of small stability which are adduced to prove that wind pressure never reaches the high values which the anemometer observations appear to show are explainable as due to the effect of the ground, and obstructions of various kinds, in screening them from the full action of the wind. The effect of obstructions is not only to reduce the general wind velocity, but to break it up into eddies and currents of small size. On large surfaces, therefore, we may expect the screening effect of obstructions to be still greater than on small surfaces.

Pressure on Solid Bodies of Various Forms.

When a solid body is presented to the wind the front pressure is modified if the face of the body is not plane, and the negative or back pressure is modified if the form of the body interferes with the convergence of the air in the wake. If we put K for the ratio of the pressure on a body to the pressure on a thin plate, of area equal to its projected area on a plane normal to the wind, then

	K=	Wind.
For a sphere	0.31	——
„ cube	0·80	Normal to face.
„ „	0·66	Parallel to diagonal of face.
„ cylinder (height = diam.)	0·47	Normal to axis.
„ cone (height = diam. of base)	0·38	Parallel to base.

On a cylindrical chimney, for instance, the wind pressure would be only about half that on a thin plate of area equal to the projected area of the chimney.

Effect of Obliquity of Surface to the Direction of the Wind.

All anemometers are placed normal to the wind's direction, and anemometer pressures are pressures on a plane struck normally. But the engineer requires to know the effect of wind action on surfaces oblique to the wind's direction. However the wind strikes a surface, the resultant pressure is normal to the surface, but this normal pressure decreases as the obliquity of the surface is greater.

A number of experiments have been made with planes moved in still air, the planes being at various angles with the direction of the motion. This is merely the converse of stationary planes in moving air. There is no rational formula expressing the results of such experiments, but there are half-a-dozen empirical formulæ which are accurate enough for the purposes of the engineer. Amongst these perhaps the simplest is that of Duchemin*. Let ϕ be the acute angle between the plane and the wind's direction, P the pressure per square foot of a plane due to the same wind striking the plane normally ($\phi = 90°$). Then for any other inclination the normal pressure per square foot is

$$N = P \frac{2 \sin \phi}{1 + \sin^2 \phi}.$$

It may be pointed out that in most experiments what was directly measured was not the resultant pressure on the surface, but the component of the resultant pressure in the direction of motion, and this has given rise to some confusion. The direct force, or force in the direction of motion, when a plane is moved in still air, decreases very rapidly with increasing inclination of surface. But the resultant or normal pressure does not decrease nearly as fast.

About 1868 some experiments on pressure on surfaces were made for the Aeronautical Society by Mr. Wenham, which are interesting in themselves, and which indicate the components of the normal pressure clearly. A plane of two square feet area was placed in the current of air from a large blowing fan. The plane was held in place by two sets of springs, one acting in the direction of the air current horizontally, and the other set at right angles to the wind current vertically. *Fig.* 5 shows the horizontal and vertical forces measured with different inclinations of the plane. If we combine these vertical and horizontal forces, we get a resultant pressure which, as should be the case, is in all cases almost exactly normal to the plane.

Distribution of Pressure on an Oblique Surface.

When wind strikes a surface normally the pressure is, as far as is known, uniformly distributed over the surface, or very nearly so. But when the plane is oblique the pressure is greater near the forward edge, and less near the edge towards which the air is flowing This appears to be true both of the positive and negative pressures. All that has been determined at present is approximately the position of the resultant of the pressure on a rectangular surface.

If a plane (*Fig.* 6) makes an angle ϕ with the direction of the wind, then the resultant of the normal pressure R divides the surface into two unequal segments of lengths a and b. For a plane

* See the Author's article on "Hydraulics," *Encyclopædia Britannica*, p. 518.

in water the following values have been found, and there is no reason to think that for air the case is different.

$\phi =$		$\frac{a}{b} =$
$72° - 75°$	... ...	0·9
$57° - 60°$	... ...	0·8
$43° - 48°$	... ...	0·7
$25° - 29°$	... ...	0·6
$13°$	... ...	0·5

Professor Kernot's Experiments on the Influence of Shelter.

When the wind strikes an oblique plane freely exposed the normal pressure is calculable with at any rate a practically sufficient approximation. But if the oblique plane is not freely exposed, but so placed relatively to other surfaces that the deviation of the current of wind is interfered with, then the pressure on the surface is greatly altered, and in a way not at present calculable. For instance, an ordinary roof is most commonly superposed on a vertical wall which interferes with the flow of the current at its lower edge. The vertical wall throws up a stream of air which interferes with the incidence of the wind on the roof, so that the roof surface lies in a kind of wind shadow. Such an effect may be termed an effect of shelter, the vertical current thrown up by the wall acting like a solid sheltering surface.

There are not many experiments on this kind of action. A few on a small scale have been made by Professor Kernot with a whirling machine.

First of all, by the aid of small flags the direction of the current deflected by a vertical plane was observed. *Fig.* 7 shows the results of these observations. The current deflected by the vertical wall took the direction shown by the dotted stream lines. Above and behind the wall was a curved space in which there was no sensible wind velocity, only irregular eddies and still air. The figures on the diagram are proportional figures, the wall height being the unit.

Next a sloping roof surface freely exposed all round, and with two different heights of wall was tried (*Fig.* 8). The roof surface was placed at various angles from 20° to 60°. The following table gives the results, and *Fig.* 8 shows the relative proportions of roof and wall:—

Inclination of Roof to Horizontal.	Normal Pressure.		
	Case A.	Case B.	Case C.
60°	95	55	75
45°	87	25	55
30°	72	10	14
20°	54	0	0

The pressure on a vertical surface equal to the roof area being 100.

The vertical wall obviously exercises considerable sheltering effect on the roof behind it, and two things may be noted:—(1). The higher the wall relatively to the length of roof the more powerful is the upward current, and the greater the sheltering effect. (2). When the angle of the roof is as low as 30° the sheltering effect is very considerable, and when it is as small as 20° the shelter is complete, and the roof is not subjected to any pressure at all.

The Forth Bridge Experiments.

During the construction of the Forth Bridge, after the serious consequences of a neglect to take adequate precautions against wind pressure had been made clear by the Tay Bridge disaster, Sir John Fowler and Sir B. Baker decided to make some experiments on wind pressure for themselves. Their researches were directed chiefly to two points—the determination of the ratio of wind pressure on small anemometer plates and on large surfaces, and the determination of the relative resistances of simple plates and bodies of complex form. To find the comparative pressure on large and small surfaces, an immense pressure plate anemometer, shown in *Fig.* 9, was constructed 20 feet long and 15 feet high, on the top of an old castle on the island of Inchgarvie. This was necessarily fixed in direction facing east and west. Beside it were erected two small anemometers having a plate area of 1½ square feet—one fixed to face east and west, the other revolving to face the direction of the wind. Between 1883 and 1890, on fourteen occasions of storm, pressures ranging from 25 lbs. to 65 lbs. per square foot were registered on the small revolving gauge. During the same period the highest pressures recorded on the east and west fixed small gauge ranged from 16 to 41 lbs. per square foot. Also during the same period pressures were registered, on the large fixed gauge of 300 square feet area, ranging from 7 to 35 lbs. per square foot. It seems reasonable to conclude that though the intensity of pressure is generally smaller on the large surface than on a small surface, yet the maximum for the large surface is not very much less than on the small surface.

For experiments on bodies of complex form, Sir B. Baker adopted a very ingenious device. Experiments in wind storms would have been difficult and inconvenient. Instead of this a light wooden rod was suspended by a cord. At one end, the complex form the resistance of which was required was fixed. At the other a small card board plane. Setting the apparatus swinging, it was obvious at once at which end of the rod the resistance was greatest. Then the area of the card board plane was altered until its resistance just balanced that of the body to be tested. In this way the areas of plane having resistance equivalent to that of various bodies of complex form was determined.

For bodies of comparatively simple form, such as cubes and cylinders, the relative resistances were found to be the same as those directly determined by earlier observers. The most interesting point to determine next was the influence of one surface in sheltering another. With discs placed at from one to four diameters apart, there was complete shelter, when the distance was one diameter, the resistance being the same as for a simple disc. The resistance was increased by 25 per cent. when the discs were $1\frac{1}{2}$ diameters apart; by 40 per cent. at 2 diameters; by 60 per cent. for 3 diameters; and by 80 per cent. for 4 diameters. Intermediate discs did not much increase the resistance. Four discs in series behind each other, with a total distance between first and fourth of $3\frac{1}{2}$ diameters, had no more resistance than two discs at 4 diameters.

Perforated discs were then tried to imitate the effect of shelter of one lattice girder on another. With openings in the discs equal to one-fourth the whole area, the discs being 1 diameter apart, the resistance of the sheltered disc was only 8 per cent. of that of the front disc. But with openings half the whole area the resistance of the sheltered disc was 30 per cent. of that of the front disc. At 2 diameters apart the resistances of the sheltered disc were 40 per cent. to 66 per cent. of that of the front disc, and at 4 diameters apart, with openings half the total area, the resistance of the sheltered disc was 94 per cent. of that of the front disc.

The top members of the Forth Bridge consist each of a pair of box-lattice girders, that is, they are nearly equivalent to four single lattice girders in series. Models of single-web girders made to imitate these were tested in pairs. With distances apart equal to once, twice and three times the depth of the girders, the resistance of the sheltered girder was 20 per cent., 50 per cent., and 70 per cent. of the resistance of the front girder. With additional girders placed between the others the increase of resistance was small. With a complete model of a bay of one top member of the bridge, that is, with the equivalent of two single-lattice girders, the total resistance was 1·75 times the resistance of a plate equal in area to the projection of one lattice girder, that is, to the projection of the solid surfaces excluding the openings.

The bottom member of the Forth Bridge consists of two tubes of circular section braced together by lattice girders. A complete model of one bay was tested. It had a resistance 10 per cent. greater than the resistance of a plane surface of the projected area of one tube.

The Board of Trade Committee of 1881.

It appeared from the investigation of the Tay Bridge disaster that that bridge was in fact blown over. It may or may not have been quite as well constructed as a lofty viaduct should be. But whatever defects of workmanship there may have been, contributing to the actual disaster, it was undoubtedly a structure with a very small margin of safety against wind pressure, even if no defects existed. In 1881 the Board of Trade, which is responsible for the inspection of railways, constituted a Committee, of engineers chiefly, to consider the proper allowance to be made for wind pressure.

As a result of these examinations the Committee recommended that for railway bridges and viaducts a maximum wind pressure of 56 lbs. per square foot should be assumed in calculation.

To this general recommendation they appended further proposals as to the mode of calculating the pressure on the structure.

(1). For a plate girder bridge with sides higher than a train, the pressure was to be taken as 56 lbs. per square foot on the whole vertical projection of one girder.

(2). For a plate girder bridge of less height than a train, the projected area of girder and train was to be taken, the train being assumed to occupy the full length of the bridge.

(3). In the case of a lattice girder bridge, the pressure was to be taken as acting on a continuous surface extending from the level of the rails to the top of the carriages, plus the vertical projected area of so much of one girder as projected above the train or below the rail level. In addition to this a further allowance was to be made for pressure on the inner or leeward girder, according to a varying scale which I need not stop to describe.

Lastly, a very important recommendation was made as to the factor of safety to be allowed. It is usual in designing bridges to allow a factor of safety of about 4 for the vertical loads. That is, for iron of a strength of about 20 tons per square inch the maximum stress is limited to 5 tons per square inch. For steel with a strength of about 30 tons per square inch the maximum stress is limited to $7\frac{1}{2}$ tons per square inch. The experience of engineers has shown that for bridges or parts of bridges for which the live load bears a large ratio to the dead load a larger factor of safety still, or what is the same thing, a lower limit of stress, must be adopted. Now in the horizontal direction in which the wind acts there is no dead load, and the wind pressure itself is virtually a live load. But, unlike ordinary live loads, it only acts with full intensity a few times in a year, and in that respect it is unlike ordinary live loads, which act on the structure many times every day. Now for the wind pressure the Committee recommended that a factor of safety of 4 should be adopted in fixing the limiting stresses.

As regards mere overturning of the bridge by wind pressure, they consider a factor of safety of 2 sufficient.

These recommendations were adopted by the Board of Trade, and practically they govern the design of structures subject to Board of Trade inspection.

In the United States of America engineers are free from any control like that exercised by our Board of Trade. It appears, however, that the rules they voluntarily adopt are not very widely different from those governing practice in this country. The principal difference, and it is interesting and rational, is that they treat the wind pressure, on the surface of the train passing over a bridge, as like a travelling load, which may act on any segment of the structure, leaving the rest unloaded. It is well known that a continuous travelling load such as a railway train produces the greatest shearing action when the longer segment into which the bridge is divided by the front of the train is loaded and the shorter segment unloaded. As the train covers the bridge the maximum shearing forces diminish.

Two American statements as to allowances for wind pressure are appended.

Mr. Shaler Smith's allowance for wind pressure:—

Mr. Smith allows for 30 lbs. per square foot on the projected area of a train (that is, 300 lbs. per foot length of train), and for 30 lbs. per square foot on twice the projected area of one truss. Further, he treats the 300 lbs. per foot length of train as a travelling load, which will produce the greatest shearing stress at any section when only the longer segment of the bridge is covered by the train. In bridges of less than 200 feet span he also calculates for the case of 50 lbs. per square foot wind pressure on twice the projected area of one truss, no train being supposed to be on the bridge. He states that experiments on a turning bridge at Rock Island in 1872 showed that the total pressure on the structure was equivalent to 1·8 times the wind pressure on the projected area of one girder.

Mr. Waddell specifies allowance for wind pressure thus:—

The total wind pressure on a railway bridge is to be divided into two parts:—One a moving load of 240 lbs. per foot run, due to wind pressure on a train moving over the bridge; the other a fixed uniformly distributed load of 30 lbs. per square foot on an area calculated thus:—Add together the area of the platform obtained by taking the product of the height from top of rails to bottom of track stringer by length of span, and twice the area of vertical projection of one truss or girder. For bridges of less than 200 feet span, they should also be calculated for the condition when unloaded or with no train on the bridge, by taking 50 lbs. per square foot on the area calculated as above.

Wind loads on unloaded bridges he treats as moving loads on the assumption that part of a bridge may be screened, and the rest subjected to the wind pressure.

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PAPER V.

MODERN SANITATION.

By W. D. Scott-Moncrieff, Esq., M. San. Inst.

In the three lectures which I have been asked to deliver to you I shall endeavour to set forth the leading principles of modern sanitation and the methods employed for putting them into practice. I shall attempt to relate the principles and the practice in such a way that they may appear together, one being the counterpart of the other, and avoiding, as far as possible, any explanations which are unconnected with these relationships.

In doing this I must ask you to follow me as closely as you can, not only in matters of detail, but more especially in the connection between the details and the principles which they embody. It is in this way that I hope to make use of the short time allotted to me with some advantage to those whose business it may be to carry out work far away from home, and in circumstances in which a clear knowledge of the principles of sanitation may suggest simple and even rudimentary methods of putting them into practice.

Perhaps I can best explain this point of view by asking you to look at these blocks of wood, representing buildings such as barracks, stables. administrative buildings, canteens, etc., made, let us say, to a scale of $\frac{1}{8}$ inch to the foot, and placed upon a plane surface also set out to scale. By tilting the board we can indicate any inclination of the ground. It will rest with the military expert to settle how the buildings should be arranged, where the administrative block should be placed in relation to the barracks, and so forth. Upon digging into the soil at various points its character may be determined, and another site selected if necessary. But what I wish to deal with this evening are the principles and practice which should guide you in arranging for the sanitation of these different buildings under every possible condition of position, of slope, of soil, and of available materials. If we place the blocks in any particular positions, and suppose that there are no sanitary materials available, the problem comes to be one of field sanitation, and with that we are not at present concerned; but if we suppose the case of an exceedingly scanty supply of materials set forth in a schedule, and then ask you to work out a scheme and a specification—the best possible under the circumstances—it is obvious that nothing but a knowledge of principles could enable you even to approximate to a successful result. In such a case the textbooks in matters of apparently necessary detail would only add to the conviction that the problem was insoluble.

If, on the other hand, I place the blocks in quite different positions, and, having worked out an elaborate scheme for their sanitation, prepare a detailed specification embodying the most recent improvements, and then extract the materials all intermingled, so as to give no clue to their proper situations, it is equally obvious that considerable knowledge of the principles of sanitation would be necessary to enable you to reproduce the specification with all the materials in their proper places. From this it is evidently a mistake to suppose that a simple acquaintance with appliances and materials is sufficient to enable you to solve both of the problems which I have suggested. More than this is necessary. It is essential that you should be able to withdraw your mind for the time being altogether from thoughts about materials and appliances and their uses, and that you should concentrate your attention absolutely upon the considerations which gave rise to their use. You should ask yourselves :—(1). What is the object of sanitation? (2). What are the conditions and circumstances which work against that object? (3). What are the best means for overcoming the obstacles which work against the attainment of the object? When these questions are intelligently answered the appliances will, as it were, fall into their proper places.

Generally speaking, it may be said that until recently the object of so called sanitation was convenience. Now it is health; and, fortunately, the one is not incompatible with the other. Let us now ask ourselves—what is health in its relation to sanitation? It has nothing to do with what we eat or drink, so long as the food and the drink are wholesome. Sanitation has only to do with health in relationship to purity—pure air, pure water, uncontaminated food. Sanitation, then, is the science of keeping air, water, and food in a condition of purity, and conversely it may be stated that the subject matter of sanitation is impurity—impurities in air, in water, and in food. The art or practice of sanitation is the art of protecting ourselves against impurity. Now you must not suppose that these are mere truisms that do not require reiteration. The next question that arises would not occur to anyone if he had not thought a good deal about the truisms of sanitation. It is this—has impurity its proper place in nature? The answer is that it has not only its place in nature, but it is such an important one that life upon this planet would be impossible without it. A world without impurity would be a sterile, and, therefore, a lifeless world. It is this paradox which forms the very foundations of modern sanitation, and with which everyone who is responsible for sanitary results should be thoroughly acquainted. Let us now, in order to resolve the paradox, think a little about what we know of the impurities with which it is the business of sanitation to contend. We know of them as existing in the air, in water, and in food—in other words, they are associated with the three states of matter, the solid, the liquid, and the gaseous, and it is with impurities in each of these conditions that sanitation has to deal. Now in other subjects it is often necessary to have a great many facts all related to each other before it is possible to form any conclusions, but in the case of impurity—the organic impurity with which we are now dealing—there is one fact that tells us what it is in a single sentence, and it is that impurity is always associated with the breaking up of more complex substances into their simpler compounds. It may be spoken of generally as wear and as decay, and when we enquire we find that in the sphere of life this process is not only universal, but it is one upon which life itself is absolutely dependent for its continuance.

You see we are now getting away from the truisms about health and sanitation, and are coming to a kind of knowledge which opens up a new view of the world we live in, and which is more and more interesting as we go on. In the light of this knowledge we now begin to realize that, after all, impurity is only a comparative term, and that decay is really an arc in the circle of life—it is the downgrade side of the circle, but when the bottom is reached the life process is again capable of ascending the circle and of re-arranging the old materials with the same infinite elaboration as before. Every separate form of life has its individual and highest point of development, the apex of its own circle, from which it again descends through the process of decay when it ceases to live, but finally provides materials for the life of another rising through the circle again. Nature is a most careful housewife, who admits of no waste in her establishment.

To many of you it may seem a long cry from the circle of life to the sanitation of a barrack room; but I hope before these lectures are concluded that you will understand how closely they are connected, and that many lives—lost through bad sanitation—have been sacrificed from ignorance of the real significance of this connection. I wish you now to keep clearly in your minds three great facts: 1st, that life, as a whole, is the building up of inorganic matter through vegetation and animals into an organic form; 2nd, that this has its counterpart in the other great fact that decay breaks down organic matter into its original inorganic forms; and 3rd, that it is the business of sanitation to provide conditions by means of which the breaking down of organic matter does not interfere with the healthy lives of the individuals it is desired to preserve. These two processes are constantly at war with each other, but they finally unite and make the circle of life complete.

Both processes are universal. To arrest decay as a whole is impossible. If successful, it would deprive every living being of the means by which it lives. But while this is true, it is often necessary to arrest decay for a particular purpose. Meat brought from the Antipodes is subjected to a strictly sanitary process when it is frozen; but this is only a temporary measure, for when it is eaten, and after it has contributed to the support of life, it passes through changes which bring it to the original inorganic condition which fed the grass which fed the sheep which fed the man. Meat, when frozen, can be conveyed for thousands of miles through the tropics and delivered in a wholesome state as food for man, and this fact would be enough in itself to show that decay is a process due to causes which can be arrested before producing their effects. I have a simple object-lesson here which will do more to prove what decay really is than many pages of explanation. I hold in my hand a small phial, which contains meat broth and gelatine expressly prepared for the nourishment of microscopic creatures which can be destroyed by being subjected to a temperature of 100°C. Now the contents which you see were subjected to this temperature in my laboratory four years ago, and in this way they were sterilized, that is to say, any life that existed at that time in the phial was destroyed. Since then it has been exposed to the heat of summer and the cold of winter during the time I have named, and the only means of preserving the nutrient preparation from decay has been this small plug of cotton-wool. Yet, you see, no change has taken place, and the contents are just as fresh as they were at the beginning. Now it is obvious that this negative condition is unconnected with the life process in any way, either in building up or in breaking down. But you cannot name any other conditions except burning by fire or destroying by chemicals under which this gelatine could have escaped from the universal law of decay at the temperature of summer unless by some such appliance as the plug of cotton wool, and we now know that the negative or fresh condition has been maintained simply by preserving it from becoming the food of microscopic creatures that are universally present in nature, and whose function it is to break down organic matter into its inorganic constituents. It is these organisms that bring the harvest to the farmer by breaking up the manure into a form that can be assimilated by the plant, and, while dealing with the down-grade of the circle of life, they are of universal beneficence, because they make the circle complete. I cannot do better than quote the eloquent language of Duclaux :—

"Whenever and wherever there is a deposit of organic matter, whether it be the case of a herb or an oak, of a worm or a whale, the work is exclusively done by small organisms. They are the important and almost the only agents of universal hygiene ; they clear away more quickly than the dogs of Constantinople, or the wild beasts of the desert, the remains of all that has had life. They protect the living against the dead ; they do more—if there are still living beings, if, since the hundreds of centuries the world has been inhabited, life continues, it is to them we owe it."

I have now to ask you to consider the third of the facts which I laid before you, viz., "that it is the business of sanitation to provide conditions by means of which the breaking down of organic matter does not interfere with the healthy lives of the individuals it is desired to preserve."

The requirements which are necessary to attain this result may be tabulated as follows :—

Section 1. Healthy conditions as regards air, water, site and situation.

Section 2. Providing for the removal of the solid and liquid waste products of man and of domestic animals.

with an ordinary cap and lining. Unless the incoming supply of water is considerable, it requires an inverted ball valve to set it in motion.

Although flushing cisterns such as I have described are important adjuncts to every drainage system, a great objection has been raised to them by water companies, especially in London, where they are entirely prohibited, unless when the water is paid for by meter, and this has been carried so far as to include small self-acting flushing tanks for urinals. There is certainly something to be said against the waste which is entailed by the use of appliances which discharge water during the night and at other times when they are not required, and to meet these objections I will now show you an appliance which is started by a current of electricity, that can be made use of either by touching buttons at a controlling centre, or by means of clock-work, switching it on at any periods of the twenty-four hours that may be thought desirable.

Referring to *Figs.* 1 and 2, *Plate* VIII. *a* is the cistern or tank, and *b c* the syphon; the long leg *c* of the syphon, has near the bottom of the cistern, a short up-turned branch *d* fitted with a valve *e*, which is connected by a chain *f* to a lever *g* connected to a float *h*. This lever has its fulcrum at one end *i*, and its other end *j* projects beyond the end of the cistern. The lever is retained in its normal position (shown in full lines in *Fig.* 1) by a catch or trigger *k*, which holds down the end *j*. The catch *k* is pivotted at *l* to a lever *m*, and can move slightly downwards, but not upwards, on this pivot. The lever *m* is itself pivotted at *n*, and its lower end carries the armature *p* of an electro-magnet *q*. *r* is a counterweight which normally keeps the armature *p* away from the electro-magnet. *s* is the float of the supply ball-cock *t*. The lever of this float (or it might be a distinct lever and float) has a pin *u*, which works in a slot *v* of a bar *w* suspended from one end of the lever *x*; to the other end of this lever is connected a switch-piece *y*, which, in the normal position, namely, when the cistern *a* is full, makes connection, as seen in the drawings, between two contact pieces *zz*, which form part of the circuit of the electro-magnet *q*.

The action of the apparatus is as follows:—The parts being in the respective positions seen in *Figs.* 1 and 2, namely, the positions they occupy when the cistern is full, as soon as the current is sent through the electro-magnet, owing to the temporary completion of the current by the clock or otherwise, as may be arranged, the armature *p* is attracted, the lever *m* therefore moves on its pivot *n*, and the catch *k* is withdrawn from the end *j* of the float lever *g*. This lever is immediately forced up to the position indicated by dots in *Fig.* 1 by the rising of its float *h*, and in rising it opens the valve *e* by means of the chain *f*. Water from the cistern rushes through the valve *e* and branch *d* into the long leg *c* and starts the syphon action. As the cistern empties, the lever *g* descends, and becomes again caught by the catch *k*, which moves slightly downwards on its pivot *l* to allow the end *j* of the lever to pass it. The ball-cock lever also descends as the cistern empties, and draws down the lever *x*, or this lever may descend at its inner end by virtue of the greater weight on this side of its fulcrum; the descent of the inner end of the lever *x* lifts the switch-piece *y* clear of the contact-pieces *zz*, so that the electric circuit is broken between them. As the cistern fills and the ball-cock lever rises, the pin *u* thereon rises in the slot of the bar *w*, and eventually, on reaching the top of the slot, pushes up the bar *w*, together with this end of the lever *x*, until the switch-piece *y* at the other end again makes contact, when the cistern is full, between the contact pieces *zz*. It will thus be seen that, even when the necessary contact is made by the clock or other alternative device, the circuit of the electro-magnet *q* cannot be completed, and therefore its armature cannot be attracted until the cistern is full. No water, therefore, can be discharged unless the cistern is full, and a proper quantity of water passes at every discharge. It is, however, not essential to provide as above described for breaking the electric circuit when the cistern empties, the break being only re-made when the cistern is full; but it is a useful provision, especially where there is a local push-button which might be the cause of the apparatus being set into operation without sufficient water being there to set the syphon going. This apparatus is, of course, not intended to take the place of an ordinary waste-preventing cistern, but as it is capable of discharging the contents of the largest flushing tanks by the small syphon starting the larger one, it enables the most extensive establishments to have their flushing carried on with economy of water from one point of central control, and also allows of the whole of the flushing to be started instantaneously.

Without referring to the ordinary tap, which is an obvious but prohibited means of supply, we now come to the non-automatic appliances, generally called water-waste preventors, and these are so numerous that it is not possible to describe them in any detail. They may be counted by scores, but I have here two drawings, which are more or less representative of the two principal types.

Waste-Preventing Cisterns.

You will notice that they are actuated in one case by a body of water being thrust over the syphon (*Fig.* 4, *Plate* I.), and in the other by the lifting of a valve (*Fig.* 5, *Plate* I.), which can only be momentarily raised from its seat, but which starts the syphon on being lifted. Here again the water companies have intervened, and insisted upon a maximum supply which is altogether inadequate. There is no doubt that one of the first acts of a new authority in London for dealing with the water supply would be to increase the amount allowed in these waste-preventing appliances by at least 30 per cent.

Besides waste-preventing cisterns, there is another well-known appliance, which is generally attached to valve closets, and which is no doubt familiar to you as the "Bellows" regulator.

Though it is not a strictly waste-preventing appliance in the sense of the cisterns just referred to, seeing that the apparatus can be propped up so as to allow of the flow of water to be continuous, I believe that in practice it is as economical as any. It consists, as you see, of a copper vessel, inside of which there is a bellows arrangement with a valve at the bottom, allowing the air to pass in freely, but which allows of the air to escape only through a small tap as the lever actuating the water supply descends, the speed being regulated by means of a small tap adjusted to any required rate of escape. I shall have to refer to it later on, when describing the valve closet, with which it is generally associated.

Although I have only given a very meagre outline of the appliances of sanitary supply, I must now go on to the next subject, which is quite as important, and which deals with

Apparatus for Utilizing the Water to the best Advantage.

Under this heading we have to deal with the whole range of closet appliances, including latrines, and here again the numbers of inventions are so numerous, embodying as they do a vast amount of ingenuity, that it will be only possible for me to refer to them in their more typical and advanced forms.

The object to be obtained is alike in all of them, and those that provide the most efficient conditions as regards cleanliness and efficient trapping may be safely looked upon as the best. From this point of view it is obvious that no surfaces should be exposed which have the chance of being rendered foul without the certainty of cleansing, and it follows that every apparatus should provide for such a volume of water as to prevent the possibility of any such accident. It is also obvious that no foul discharges should ever be retained in the body of the apparatus, and in this respect the ordinary latrine, which is only flushed at lengthy intervals of time, must be condemned as being wanting in one of the first conditions of good sanitation. Latrines either take the form of separate closets connected with a pipe in common to all of them (*Fig.* 1, *Plate* II.), or the form of troughs with a weir at the outlet end which regulates the height of the water (*Fig.* 2). In all these appliances the sanitary efficiency depends upon ample and frequent flushing.

We next come to a certain class of earthenware appliances, which are no doubt familiar to you. In the various forms I shall now refer to they may be classified as follows, viz. :—

1st. Hopper closets, so called from their shape (*Figs.* 1 and 2, *Plate* III.).

2nd. Wash-outs (*Figs.* 3, 4 and 5).

3rd. Wash-downs (*Fig.* 6).

4th. Syphonic (*Fig.* 7).

5th. Valve apparatus (*Fig.* 8).

I shall not make any reference to the old form of pan closet, which may now, fortunately, be looked upon as obsolete and universally condemned.

There are two kinds of hopper closets, which differ only in the manner in which the water is applied to them; in the one case it enters the basin at a single point, and is directed in such a way as to provide as far as possible for the whole internal surfaces being washed by it. In the other there is a flushing rim, which affects them, on the whole, more effectually, but in neither case can the result be looked upon as satisfactory.

The next form, which has been greatly in vogue for the last ten or twelve years, is known as the wash-out. The trapping differs in many of them, and the shape is arranged as far as possible to meet requirements of cleanliness; but here again experience has proved them to be defective, and they are no longer being recommended by sanitary experts on account of their tendency to become foul. The next form is the wash-down. This is a modified hopper in which there is less surface exposed to the risks of being fouled, and in which every effort has been made to provide as large a volume of water in the apparatus itself as possible. The difficulty in making this sufficient lies in the small quantity of water available in a 2-gallon waste-preventing cistern, one discharge from which is found to be altogether inadequate to remove a large body of water already in the basin. There is no doubt that an additional gallon of water in the flushing cistern would admit of a considerably larger provision of water in the basin of the apparatus, and this of itself would raise the sanitary standard of all these appliances very considerably. As the line drawn by the water companies is hard and fast, an immense amount of ingenuity has been expended upon devising an apparatus in which the efficiency of the incoming water would be supplemented by a sucking action taking place upon the water already contained in the basin, by establishing a partial vacuum in the passage of discharge. One of these syphon-action closets is shewn (*Fig.* 7, *Plate* III.).

Anyone interested in these appliances will find two interesting chapters on the subject in Mr. Hellyer's book on plumbing.* He states that the first patent granted in this country for water closet apparatus was in 1775, 158 years after the Patent Laws had been introduced, but that the specification spoke of a water closet upon a new construction, showing that these appliances must have been in use at the time. This patent was taken out by a certain Alexander Cumming, a watchmaker in Bond Street, and is to all intents and purposes a valve closet with a sliding valve. Three years afterwards Bramah took out a patent for a similar apparatus, having a clack valve opened and closed by its spindle, and Mr. Hellyer refers to this as "The well-known Valve Closet."

It is needless to say that, with such a variety of appliances, there is a great diversity of opinion as to their rival merits, and it is, therefore, better not to dogmatize; but, speaking for myself, and as the result of a somewhat extensive experience, it is my opinion that, excluding the pan closet, and closets with plugs, it may be stated generally that they are all good from a sanitary point of view, when they are provided with an unlimited supply of water, and when they are properly trapped, but that their merits are immediately differentiated when the water supply for a flush is limited to two gallons. I may say, further, that, from the point of view of the maximum of flush from a minimum of water, the valve closet is without a rival. An advanced example of this apparatus is shown (*Fig.* 8, *Plate* III.), and an improved form of valve (*Fig.* 3, *Plate* IX.).

* *Principles and Practice of Plumbing*, by S. Stevens Hellyer. Bell & Sons, London, 1891.

LECTURE II.

In the last lecture I attempted, first of all, to point out the great importance of a knowledge of the principles upon which successful sanitation depended. I then referred to the natural operations of growth and of decay, and showed that the one was the counterpart of the other, and that both were necessary to the continuance of life, under existing conditions, on our planet. I next dealt with the province and business of sanitation, which is neither more nor less than providing conditions by which the individual whose healthy life it is the object to preserve should be protected against the external process of decay. I next referred to the means by which this object may be attained, and concluded by an explanation of the methods employed for the removal of the waste products of man and of domestic animals by the system of water-carried sewage, dealing first with the apparatus of supply, and next with the apparatus of use. In this lecture I shall have, first of all, to conclude the subject of removal by a description of the most advanced forms of drains, excluding sewers, dealing with the materials and methods of jointing them, or, more properly speaking, of joining them securely together. I shall then have shortly to refer to the means which should be provided for the inspection and cleansing of the drains when laid, and afterwards I shall have to treat the third great requirement of modern sanitation, viz., the provision of means for preventing the intrusion of gases arising from the breaking up of organic wastes, which will include the subject of disconnection, of trapping, and also the ventilation of pipes and drains.

Materials Used for the Construction of Drain Pipes.

The materials used for the construction of drain pipes are practically confined to stoneware and cast iron. The disadvantage of the former consists chiefly in the short lengths in which they are manufactured, requiring a large number of joints, and their liability to fracture; and conversely the advantages of cast iron are: (*a*), the long lengths in which it can be manufactured; (*b*), the corresponding reduction in the numbers of joints as compared with stoneware; (*c*), its superior strength and capacity to resist fracture; (*d*), the facilities afforded for making strong and reliable joints; (*e*), the adaptability of the material to every variety of form.

Until recently, stoneware pipes have been used to the exclusion of all other materials, but they have this great disadvantage, in addition to those I have already mentioned, that, even when laid with the greatest skill, they are not suited to stand the test of water pressure which is now generally applied to them. If this be the case, the comparative merits *per se* of the rival materials, earthenware and cast iron, becomes a question for merely academic discussion if it can be shown that the latter is capable of standing the test for a sufficient number of years to justify its adoption on the score of permanence. In other words, the suitability in other respects of stoneware becomes valueless if there is no certainty that it will pass the standard which is now universally applied to it. It appeared to me many years ago that, under the test of water pressure, the use of stoneware pipes, especially beneath buildings, must be definitely abandoned, and I have long ceased to employ them. The loss of money which has befallen the householders of our large towns through the use of stoneware drains is simply incalculable, and though I think it may be reasonably maintained that in many cases where a slight leakage occurs the danger to health arising from it is practically negligable, the fact remains that an intending purchaser or tenant who takes advantage of the water test to protect himself can allege that the drains are defective if they leak at all. On this account it frequently occurs that houses in London are re-drained over and over again within a few years, each new occupier or purchaser having them re-laid only to find that they are again inadequate to stand the water test at the end of the tenancy.

Cast-Iron Drains.

The points to be considered in adopting cast-iron drains are as follows :—(*a*). The available means for preserving it ; (*b*), the determination of the capacity and weight of the pipes ; (*c*), the character of the connections best suited to the material ; (*d*), the nature of the joints ; (*e*), the comparative cost.

With regard to the life of cast iron for domestic drainage, the following statement may be accepted in general terms :—(1). All pipes of inclination which come in contact with ordinary sewage show no sign of interior rusting even after many years of use, owing to the greasy nature of the liquid discharged ; (2), the same remarks apply to vertical pipes washed with sewage ; (3), no ventilating pipe should be made of cast iron, because it rusts rapidly from exposure to the gases from domestic sewage as well as from the air of towns—from this it follows that it is safer to make all vertical soil and ventilating pipes of lead, and when lead is used for pipes of inclination they should be supported throughout their entire length to avoid sagging.

Having once adopted cast iron, the facilities for perfecting the details of domestic drainage become enormously increased. In the case of stoneware appliances, they must be worked in as they come from the pottery, and it is not safe in many cases to attempt to chip them or alter their shape in any way. With cast iron, however, it is different, because by altering a pattern for the foundry the molten metal can be poured into any shape required, and the possibilities of meeting the peculiarities of every case are unlimited.* As the whole structure is jointed in the same way as water mains, it is capable of standing a test of water a hundred times in excess of the daily pressure, which is practically *nil*. The sense of security which is obtained under such conditions is an ample return upon any small additional cost which may be incurred, though, as a matter of fact, in many cases the one material is just as cheap in first cost as the other, while in value there is no comparison.

But cast iron has another advantage, inasmuch as it enables us to avoid the expense which is necessary to ensure that man-holes, which are frequently filled with water to test the drains, should be tight as well, and it also enables us to ensure a more rapid current for ventilation without large accumulations of contaminated air, as in the case of ordinary inspection chambers.

Here are several specimens of cast-iron drainage details such as I have been using in my own practice for many years (*Plates* IV., V. and VI.). In what has been said, no objection is raised to the mere filling of an earthenware drain outside a dwelling with a pressure of about 1 lb. on the square inch, in order to make sure that the joints have been properly made, but after being satisfied that the work is good, it is futile to subject the materials to a strain which, on the face of it, they are totally unfitted to stand.

In conclusion, I should mention that in the United States of America they have long recognized the superior merits of cast iron, and that in certain cities its use is made compulsory.

I have just described what appears to be, at least in the light of

* That the difference between cast iron and stoneware is not a mere matter of theory is shown by the fact that a well-known sanitary engineering company in London are prepared to guarantee their cast-iron drainage for 10 years, while they would decline to give the same guarantee for stoneware drains during a fortnight.

our present knowledge, the best materials to be used for the pipes, and as these have above all things to be gas-tight, especially beneath buildings, it will be well to say something of the regulations which are laid down by certain local authorities with regard to them. It is unfortunate that in a great community like London these regulations are not more uniform than they are, emanating as they now do from a number of vestries. I know of cases in which architects have been obliged to change their arrangements at the last moment, and to alter their contracts, not in order to comply with more advanced requirements than they had provided for in their specifications, but in order to meet the demands of some vestry which happens to be years behindhand in the knowledge of the subject which it is their business to control.

The following are the regulations of what may be taken as one of the most advanced vestries in London, viz., that of Kensington, as regards house drains, and it should be noted that the Public Health (London) Act, 1891, while it applies to the whole of London, only regulates the construction of the sanitary arrangements of houses under by-laws issued by the London County Council under Section 39 (1), leaving the question of drainage to be settled according to the conflicting views to which I have just referred.

By-Laws made under Public Health (London) Act, 1891.

By-Laws under Section 39 (1).

1. *Water-closets and Earth-closets.*—Every person who shall hereafter construct a water-closet or earth-closet in connection with a building, shall construct such water-closet or earth-closet in such a position that, in the case of a water-closet, one of its sides at the least shall be an external wall, and in the case of an earth-closet two of its sides at the least shall be external walls, which external wall or walls shall abut immediately upon the street, or upon a yard or garden or open space of not less than 100 square feet of superficial area, measured horizontally at a point below the level of the floor of such closet. He shall not construct any such water-closet so that it is approached directly from any room used for the purpose of human habitation, or used for the manufacture, preparation, or storage of food for man, or used as a factory, workshop, or workplace, nor shall he construct any earth-closet so that it can be entered otherwise than from the external air.

He shall construct such water-closet so that on any side on which it would abut on a room intended for human habitation, or used for the manufacture, preparation, or storage of food for man, or used as a factory, workshop, or workplace, it shall be enclosed by a solid wall or partition of brick or other materials, extending the entire height from the floor to the ceiling.

He shall provide any such water-closet that is approached from the external air with a floor of hard, smooth impervious mtaerial, having a fall to the door of such water-closet of half an inch to the foot.

He shall provide such water-closet with proper doors and fastenings.

Provided always that this by-law shall not apply to any water-closet constructed below the surface of the ground and approached directly from an area or other open space available for purposes of ventilation, measuring at least 40 superficial feet in extent, and having a distance across of not less than 5 feet, and not covered in otherwise than by a grating or railing.

2. Every person who shall construct a water-closet in connection with a building, whether the situation of such water-closet be or be not within or partly within such building, and every person who shall construct an earth-closet in connection with a building, shall construct in one of the walls of such water-closet or earth-closet which shall abut upon the public way, yard, garden, or open space, as provided by the preceding by-law, a window of such dimensions that an area of not less than 2 square feet, which may be the whole or part of such window, shall open directly into the external air.

He shall, in addition to such window, cause such water-closet or earth-closet to be provided with adequate means of constant ventilation by at least one air-brick built in an external wall of such water-closet or earth-closet, or by an air-shaft, or by some other effectual method or appliance.

3. *Water-closets.* – Every person who shall construct a water-closet in connection with a building shall furnish such water-closet with a cistern of adequate capacity for the purpose of flushing, which shall be separate and distinct from any cistern used for drinking purposes, and shall be so constructed, fitted, and placed as to admit of the supply of water for use in such water-closet, so that there shall not be any direct connection between any service pipe upon the premises and any part of the apparatus of such water-closet other than such flushing cistern.

Provided always that the foregoing requirement shall be deemed to be complied with in any case where the apparatus of a water-closet is connected for the purpose of flushing with a cistern of adequate capacity, which is used solely for flushing water-closets or urinals.

The Vestry consider that, for the effectual cleansing of water-closets, water-waste preventors to discharge 3 *gallons should be fixed.*

He shall construct or fix the pipe and union connecting such flushing cistern with the pan, basin, or other receptacle with which such water-closet may be provided, so that such pipe and union shall not in any part have an internal diameter of less than $1\frac{1}{4}$ inch.

He shall furnish such water-closet with a suitable apparatus for the effectual application of water to any pan, basin, or other receptacle with which such apparatus may be connected and used, and for the effectual flushing and cleansing of such pan, basin, or other receptacle, and for the prompt and effectual removal therefrom and from the trap connected therewith of any solid or liquid filth which may from time to time be deposited therein.

He shall furnish such water-closet with a pan, basin or other suitable receptacle of non-absorbent material, and of such shape, of such capacity, and of such mode of construction as to receive and contain a sufficient quantity of water, and to allow all filth which may from time to time be deposited in such pan, basin or receptacle to fall free of the sides thereof and directly into the water received and contained in such pan, basin, or receptacle.

The Vestry consider that the requirements of this by-law will be complied with provided the closet has an effectual trap and water remains in basin.

Cottage pattern closets will be allowed provided water remains above the joint between the trap and basin.

He shall not construct or fix under such pan, basin or receptacle any "container" or other similar fitting.

He shall construct or fix immediately beneath or in connection with such pan, basin or other suitable receptacle an efficient syphon trap, so constructed that it shall at all times maintain a sufficient water seal between such pan, basin or other suitable receptacle and any drain or soil pipe in connection therewith. He shall not construct or fix in or in connection with the water-closet apparatus any **D** trap or other similar trap.

If he shall construct any water-closet or shall fix or fit any trap to any existing water-closet or in connection with a soil pipe which is itself in connection with any other water-closet, he shall cause the trap of every such water-closet to be ventilated into the open air at a point as high as the top of the soil pipe, or into the soil pipe at a point above the highest water-closet connected with such soil pipe, and so that such ventilating pipe shall have in all parts an internal diameter of not less than 2 inches, and shall be connected with the arm of the soil pipe at a point not less than 3 and not more than 12 inches from the highest part of the trap, and on that side of the water seal which is nearest to the soil pipe.

4. *Soil Pipes.*—Any person who shall provide a soil pipe in connection with a building to be hereafter erected shall cause such soil pipe to be situated outside such building, and any person who shall provide or construct or re-fit a soil pipe in connection with an existing building shall, whenever practicable, cause such soil pipe to be situated outside such building, and in all cases where such soil pipe shall be situated within any building shall construct such soil pipe in drawn lead, or of heavy cast iron jointed with molten lead and properly caulked.

He shall construct such soil pipe so that its weight in proportion to its length and internal diameter shall be as follows :—

Diameter.	Lead.	Iron.
	Weight per 10 feet Length. Not less than	Weight per 6 feet Length. Not less than
$3\frac{1}{2}$ inches.	65 lbs.	48 lbs.
4 ,,	74 ,,	54 ,,
5 ,,	92 ,,	69 ,,
6 ,,	110 ,,	84 ,,

The Vestry consider that pipes of the weight set out in the above table, are not required to be fixed outside a building, and that ordinary iron pipes jointed with red lead may be allowed.

Every person who shall provide a soil pipe outside or inside a building shall cause such soil pipe to have an internal diameter of not less than $3\frac{1}{2}$ inches, and to be continued upwards without diminution of its diameter, and (except where unavoidable) without any bend or angle being formed in such soil pipe, to such a height and in such a position as to afford by means of the open end of such soil pipe a safe outlet for foul air, and so that such open end shall in all cases be above the highest part of the roof of the building to which the soil pipe is attached, and, where practicable, be not less than 3 feet above any window within 20 feet measured in a straight line from the open end of such soil pipe.

Galvanized iron ventilating pipes will be allowed, provided they are of the same internal diameter as the soil pipe.

As regards the height at which the ventilating pipe shall terminate, this will be complied with provided such pipe is carried at least 4 feet above the head of the highest window.

He shall furnish the open end of such soil pipe with a wire guard covering, the openings in the meshes of which shall be equal to not less than the area of the open end of the soil pipe.

In all such cases where he shall connect a lead trap or pipe with an iron soil pipe or drain he shall insert between such trap or pipe and such soil pipe or drain a brass thimble, and he shall connect such lead trap or pipe with such thimble by means of a wiped or overcast joint, and he shall connect such thimble with the iron soil pipe or drain by means of a joint made with molten lead, properly caulked.

The provision of a brass thimble in the junction of lead and iron soil pipes will be enforced only where the junction is inside a building.

In all such cases where he shall connect a stoneware trap or pipe with a lead soil pipe he shall insert between such stoneware trap or pipe and such soil pipe a brass socket or other similar appliance, and he shall connect such stoneware trap or pipe by inserting it into such socket, making the joint with Portland cement, and he shall connect such socket with the lead soil pipe by means of a wiped or overcast joint.

In all cases where he shall connect a stoneware trap or pipe with an iron soil pipe or drain, he shall insert such stoneware trap or pipe into a socket on such iron soil pipe or drain, making the joint with Portland cement.

He shall so construct such soil pipe that it shall not be directly connected with the waste of any bath, rain-water pipe, or of any sink other than that which is provided for the reception of urine or other excremental filth, and he shall construct such soil pipe so that there shall not be any trap in such soil pipe or between the soil pipe and any drain with which it is connected.

5. *Water-closets.*—A person who shall newly fit or fix any apparatus in connection with any existing water-closet shall, as regards such apparatus and its connection with any soil pipe or drain, comply with such of the requirements of the foregoing by-laws as would be applicable to the apparatus so fitted or fixed if the water-closet were being newly constructed.

14. Every person who shall intend to construct any water-closet, earth-closet or privy, or to fit or fix in or in connection with any water-closet, earth-closet or privy any apparatus or any trap or soil pipe shall, before executing any such works, give notice in writing to the clerk of the Sanitary Authority.

Rules as to the Construction of House Drains, etc.

1. All persons proposing to form new, or to re-construct or partly re-construct old house drains, shall give due notice at the office of the Vestry's Surveyor.

2. The notice shall be given on a printed form, to be obtained at the Surveyor's office, and on which shall be drawn a plan of the premises proposed to be drained, to a scale of 8 feet to an inch, with all lines of proposed drains and their branches and inlets shown thereon in red, with the proposed size of the drains, the nature of the inlets, and the depth of the lower floor of the premises below, or its height above (as the case may be) the level of the pavement outside the said premises.

3. Drains should be kept outside the house whenever practicable.

4. The main drains should be of approved glazed stoneware, laid in a direct line to a point near the surface of the ground in the rear or higher end, where practicable, for the purpose of passing a machine through the main portion in case of stoppage.

5. All drains shall be of the sizes and diameters as ordered by the Vestry. All stoneware pipes shall have a thickness of at least one-eighth their internal diameter.

6. All junctions of one line of drain pipe with another shall be made at the sides of the pipes, and not at the top, by means of properly formed junction pipes, curved junctions or obtuse-angled junctions being in all cases used where practicable, no **T** or right-angled junctions being allowed, except where absolutely necessary. Taper pipes shall be used where the size of drain is reduced in the general run. Man-holes, with channel pipes and moveable covers, should be provided where necessary.

7. All drains shall be laid with a fall toward outlet of at least $1\frac{1}{2}$ inch in 10 feet. The pipes, exclusive of joints, shall, where directed, be bedded on Portland cement concrete, and after the joints have been examined and the drains tested by the Vestry's Surveyor or his assistant, the entire drain, or the collars and joints only, or any part thereof, shall be bedded on and surrounded with concrete to such depth and thickness as he may direct. No drain shall be deemed to have been laid to the satisfaction of the Vestry until it has been tested to the satisfaction of the Surveyor or his assistant.

8. The pipes are to be put together with great care, the butt end of one pipe being forced into the socket end of the next pipe as

closely as the nature of the pipes will permit, and the ring or space between them shall be filled with Portland cement of good quality. The cement shall be well and thoroughly worked in, so as to effectually fill the whole of the space, and a band of cement shall be carefully worked round and outside of the pipe to the thickness of the outside of the socket, so as to completely cover the joint. The inside of each pipe as laid shall be carefully cleaned, so as to remove any projecting cement.

9. The connection between the house drain and the public sewer and the portion of the drain that is beneath the public way shall be made by the workmen of the Vestry, and the party requiring the drain shall deposit with the Vestry a sum of money to be estimated by the Vestry's Surveyor, to pay the expense of such connection and length of new drain, and any other works in connection therewith ; and also the cost of the re-instatement of the public-way disturbed by reason of the works.

10. All surface drains, sinks, gullies, rain-water pipes and other connections shall be well and efficiently trapped by syphon or other approved trap before being connected with the drain. Where necessary, rain-water pipes shall discharge over trapped stoneware gullies.

11. Scullery sinks should discharge into or over properly trapped catch-pits for preventing fat, etc., from passing into drains.

12. Water-closets will not be allowed to be formed beneath the public-way without the sanction of the Vestry.

13. Soil pipes, where formed inside the building, shall not be built into the wall, but may be fixed in chases, and shall be made accessible throughout their entire height. All junctions with soil pipes should be exposed to view, and easily accessible.

14. Drains are to be ventilated to the satisfaction of the Vestry's Surveyor, with special ventilating pipes (in addition to soil pipes) if directed.

15. Waste-water pipes in the upper floors of premises, if connected with rain-water pipes, shall be connected with such pipes only as are outside the buildings, and the junctions shall be made at such points outside the building as shall be easily accessible at all times.

16. The main line of drain before its point of connection with the public sewer should be trapped outside the house by means of an approved syphon trap provided with a fresh-air inlet.

17. All premises shall have good and sufficient water supply with all necessary supply pipes, service cisterns, fittings, and apparatus.

18. The overflow or warning pipe of every cistern shall have no

direct communication with a soil pipe or drain; but this regulation shall not be construed to prohibit the provision of an air-tight washer waste for cleansing purposes.

19. Baths, sinks (other than scullery sinks) and fixed wash-basins should have no direct communication with drains.

20. The whole of the works in connection with the drains shall be executed with the best materials, and in the most workmanlike manner, in accordance with the directions herein set forth, and to the satisfaction of the Surveyor, Inspector or other officer appointed by the Vestry, and his directions in all matters relating to the work as to the lines of drains, their depths, sizes, inclinations, mode of trapping, quality of materials or workmanship, shall be carried out. No portion of any drain or works in connection therewith shall be covered in until it has been inspected and approved by such officer of the Vestry, and at least twenty-four hours' notice shall be given at the Surveyor's Office by the person forming the drain when the works are ready for such officer's inspection; and if any drain is covered in without such notice being given, the Vestry may, by its own workmen, proceed to open up and uncover the said drain, and charge the expense of doing so, and of subsequently making good the same, on the party so neglecting.

21. All old brick and other disused drains abolished shall be broken up and destroyed, and the materials forming them, and all foul and sewage-charged earth and other substances, carefully removed from the premises, dry earth, or ballast, or brick rubbish being brought in if necessary in place of them, or the said disused drains shall be filled up to the satisfaction of the Surveyor.

22. Any person who shall by any works or by any structural alteration of any premises render the further use of a cesspool or privy unnecessary, and the owner of any premises on which shall be situated a disused cesspool or privy, or a cesspool or privy which has become unnecessary, shall completely empty such cesspool or privy of all fæcal or offensive matter which it may contain, and shall completely remove so much of the floor, walls and roof of such privy or cesspool as can safely be removed, and all pipes and drains leading thereto or therefrom, or connected therewith, and any earth or other material contaminated by such fæcal or offensive matter. He shall completely close and fill up the cesspool with good concrete or with suitable dry clean earth, dry clean brick rubbish, or other dry clean material, and where the walls of such cesspool shall not have been completely removed, he shall cover the surface of the space so filled

up with earth, rubbish or material with a layer of good concrete 6 inches thick. Every person who shall propose to close or fill up any cesspool or privy shall, before commencing any works for such purpose, give to the Sanitary Authority for the district not less than forty-eight hours' notice in writing, exclusive of Sunday, Good Friday, Christmas Day or any Bank Holiday, specifying the hour at which he will commence the closing and filling up of such cesspool or privy, and during the progress of any such work shall afford any officer of the Sanitary Authority free access to the premises for the purpose of inspecting the same.

23. *Any person objecting to the requirements of the Surveyor can appeal to the Works and Sanitary Committee of the Vestry.*

By Order of the Vestry,

WM. WEAVER, *Surveyor.*

THE JOINTING OF PIPES.

And now, dealing with the subject of how best to prevent the escape of gases from pipes, we come to the methods by which they should be secured one to the other—in other words, joints. For information about jointing or joining of lead pipes, I cannot do better than refer you to Mr. Hellyer's book on plumbing, where he devotes more than four whole chapters to an exposition of the subject in the most practical way. The first chapter is taken up with the essential points for good joints—length of joints, joint wiping with or without an iron, solder for making joints, shaving and turning the pipes, fitting and fixing the pipes, and a table of the proper lengths of joints. The second chapter is devoted to an explanation of underhand joints, upright joints, lead collars, use of the splash stick, overcast joints. The third chapter deals with block joints, lead flanges, close-fitting jointing, flange joints, taft joints, branch joints, mitre joints, the branch pipe to fit inside the main pipe. The fourth chapter is taken up with the copper-bit joint, ribbon joint, overcast ribbon joint, blow-pipe joint, astragal jointing, elbow joint, and elbow mitre joint.

It is obvious that it would be beyond the scope of these lectures to deal with such a very technical subject in detail, but generally it may be stated that everyone who is responsible for the supervision of sanitary works should be able to judge whether or not a joint is properly made, not when finished, for then it is practically impossible to form any opinion, but in the process of being made. The skill which is shown by a workman in turning out a joint which, to quote Mr. Hellyer, "is true in form and clean at the edges" may be taken as a fair guarantee that it complies with the third requirement of being "free from solder inside," though this, as a rule, is very hard to determine after the joint is made. In no case should the solder spread beyond the surface that has been expressly prepared for it by shaving, because it is by adhering to this rule that a judgment can best be formed as to whether it be sound or not. Another rule is that joints should, in all cases, seeing that they are necessary evils, be as few as possible, a remark I think which applies quite as much to drains as pipes. The proper lengths for the different joints is of great importance, but when this has been determined, it is just as important that the joint should be sufficiently thick to stand any strain that may be brought upon it. With a little experience these proportions can easily be indentified, as there is a peculiar symmetry about a well-made joint that can never be mistaken. Perhaps the best joint for upright pipes, both on account of strength and appearance when fixed outside a building, is the soldered joint with astragals and tacks. There is one here which has many advantages. The beads upon the socket which hold the pipe are hollow, and the joint is made by removing half of the bead, which leaves a socket, with which the upper end of the lower pipe is carefully "tafted;" then, when the lower end of the upper pipe, already prepared, is dropped into the socket, there is a space left for the solder all round the joint, and this is made stronger by solder being added to make up the contour of the bead, so as to be uniform in appearance with the one beneath. In connection with this subject of jointing, there is the familiar method of joining pipes together by means of what is known as the cap and lining. This is still in universal use for the connection of pipes of small diameter to various appliances such as lavatories, baths, cisterns, and so on, but it is never used for permanently joining the lengths of pipes together when a soldered wiped joint is possible.

The joining of lead pipes to iron ones is a matter of special importance, because the one material is so much softer than the other that, without some special appliance, it would be always subject to injury affecting the safety of the joint itself. To effect this security, the lead pipe is slipped inside a brass collar or sleeve piece, as it is generally called, and soldered by means of a blow pipe, the brass collar is then inserted into the socket of the iron pipe, and should be of sufficient thickness and solidity to admit of its being caulked with oakum and lead (*Fig.* 1, *Plate* IX.).

Jointing of Stoneware Pipes.

Coming now to the jointing of stoneware pipes, it is to be noted in the first place that they require a greater number of joinings than any other material for a given distance, and this is evident when it is remembered that they are generally made in 2-foot lengths. The ordinary method of jointing is by means of spigot and socket connections, and the permanent means of attachment is by cement, either used neat or with equal quantities of clean, washed sand. In order to provide for easy, or at least comparatively easy access when making joints, it is a good plan to lay the pipes in concrete, supporting them for about 8 inches from each of their centres, and allowing the ends of the pipe to overhang. In this way, while the pipes can be securely held as the concrete sets, they can at the same time be butted up one against the other, and an opportunity is obtained for seeing that they are accurately concentric before the cement is applied. Even with such an arrangement as this the pipes must be laid piece-meal, because one of the essential points in the process is to be able to scrape away any cement that may have been forced through the joint to the interior of the pipe, where, if it were allowed to remain, it would set, and form a very serious kind of obstruction. It has long appeared to me that such a structure, even when the greatest possible skill is available, is altogether unsuited to being tested under a pressure of water, and I have long since abandoned it wherever such a test, when it exceeds a few inches of head, is to be applied to it.

The difficulties which I have just referred to have led to the introduction of innumerable devices for overcoming them, one being the formation of accurately fitting surfaces, which are made of materials such as compositions of asphalt, which are certainly less stable in their character than the material of the pipes themselves; I have here one or two specimens. I have long been saved from any anxiety as to the efficiency of these methods by having altogether abandoned them.*

Coming now to the jointing of iron pipes. While there are several ways in which this can be effected, the plan which is generally adopted is so secure that upon that score there is nothing more to be desired. It consists of first caulking the socket after the spigot

* The best known of these joints are Stanford's, Hassal's, Sykes', Archer's and Doulton's, some of them having closely fitting surfaces, and others making provision for liquid cement being poured in, so as to form a ring.

end of the pipe is in its place, with strands of oakum, then forming a matrix round the outside of the joint with clay, pouring in molten lead through an opening in the top of the band of clay, trimming off the extra metal, and finishing with a good stout hammer and caulking iron. It is needless to say that such a method is not applicable to a stoneware pipe.

The Exclusion of Gases from Buildings.

We now come to the third section of our subject, which is as important as any, namely, providing means for preventing the intrusions of gases arising from the breaking down of organic wastes. This subject, of course, includes the efficiency of the pipes, of which we have just been speaking, but it more especially includes the whole practice of trapping and disconnection, and embraces the provisions which are found to be necessary to make them effective by avoiding the traps being forced or syphoned out, and also the provision for effective ventilation of all drains and pipes. I shall now say something about the gases themselves in relation to the dangers to health with which they have long been associated.

There is an obvious tendency amongst reasonable beings to relate events in the order of cause and effect when they recur so persistently that they cannot be explained on the theory of coincidence, and it is this simple inductive kind of reasoning which often leads a physician to suspect that some defects in the drainage arrangements of a house are more or less accountable for outbreaks of such diseases as typhoid fever and diphtheria. General health statistics all go to prove the connection which exists between bad sanitation and disease, as the death-rate is now looked upon as an index to the sanitary condition of every community. We are now possessed of more specific information as to the certainty of this connection, and I shall refer very shortly to the recent experiments of Dr. Guiseppe Alessi, an Italian bacteriologist. He says :—

"The fact (which with English sanitarians is a dogma of practical hygiene) that infectious diseases, and especially typhoid fever, are connected with bad exhalations is most important. The English hygienists, therefore, consider as injurious to health and life emanations which may escape into houses through defective construction of sewers and closets, from accidental flaws in waste pipes, or from any other imperfection in the system of the pipes for carrying away the refuse. And it is precisely this idea which has brought about the good hygienic arrangement in houses in England, to which also sanitary legislation has contributed, and the diffusion in a popular form of the rules necessary to protect houses from any putrid exhalations. This idea of the English hygienists, having been carried out, has given the most magnificent results, therefore it is useful to see if it has any experimental scientific basis, and this is what forms the subject of this paper."

Dr. Alessi then goes on to describe his experiments, and first I ought to explain to you in a few words that typhoid fever is characteristically human disease, and that any experiments that have been made upon other animals by inoculating them with the typhoid

No. 1.

Number.	Days on which the animals have been subjected to experiment.	Days on which the animals have been inoculated.	Number of prepared animals.			Number of animals in control experiment.		
			Inoculated.	Died.	Survived.	Inoculated.	Died.	Survived.
I.	Nov. 28, 1892 ...	December 3 ...	2	0	2	2	0	2
II.	Dec. 5, ,, ...	December 20 ...	3	2	1	8	1	7
		December 23 ...	3	2	1			
		December 26 ...	2	2	0			
		January 2, 1893	2	2	0			
III.	Jan. 4, 1893 ...	January 12, ,,	3	1	2	6	0	6
		January 18, ,,	3	2	1			
		January 20, ,,	2	2	0			
IV.	Jan. 15, ,, ...	January 20, ,,	2	2	0	8	1	7
		January 28, ,,	4	4	0			
		January 30, ,,	3	2	1			
		February 3, ,,	3	3	0			
V.	Feb. 4, ,, ...	February 12, ,,	4	2	2	8	0	8
		February 16, ,,	2	1	1			
		February 20, ,,	2	2	2			
VI.	Feb. 24, ,, ...	March 9, ,,	2	1	1	9	1	8
		March 28, ,,	1	1	0			
		April 2, ,,	2	2	0			
		April 26, ,,	2	2	0			
		May 7 ,,	2	2	0			
		Totals	49	37	12	41	3	38

No. 2.

Number.	Days on which the animals have been put to breathe putrid gases.	Days on which the animals have been inoculated.	Number of prepared animals.			Number of animals in control experiment.		
			Inoculated.	Died.	Survived.	Inoculated.	Died.	Survived.
I.	March 16	April 2	4	4	0	3	0	3
		April 15	4	3	1	3	0	3
II.	April 19	May 3	5	5	0	4	0	4
		May 7	6	6	0	4	0	4
III.	May 7	May 20	6	6	0	4	0	4
IV.	May 25	June 5	4	3	1	3	0	3
		June 12	6	4	2	4	0	4
		July 7	2	2	0	2	0	2
V.	June 30	July 7	4	4	0	3	0	3
		July 14	4	3	1	4	0	4
		August 27	1	1	0	1	0	1
VI.	July 16	July 24	7	5	2	4	0	4
VII.	July 25	August 11	8	5	3	5	0	5
		August 27	7	4	3	4	0	4
		September 21 ...	4	2	2	2	0	2
		Totals	72	57	15	50	0	50

bacillus have been comparatively valueless, because the animals differed from men in this respect—that they are comparatively immune to its influence. The great importance of these experiments is that they show that animals that are immune to the action of the bacillus of typhoid fever under ordinary circumstances become liable to that disease, and take it under the unfavourable conditions provided in these experiments. The natural conclusion is that, if animals, which are naturally immune to the disease, take the fever under these insanitary conditions, human beings, who are naturally liable to the disease, will take it much more readily. Dr. Alessi says:—

"The idea by which I have been guided in my experiments is this: to see what effects are produced by the typhoid bacillus, even when attenuated, in animals put to breathe in surroundings defiled by putrid gases. Should these researches give positive results, I should be able to reveal whether there really exists a relation between putrid exhalations and the predisposition of the organisms of typhoid fever.

"The experiments were made on rats, guinea-pigs, and on rabbits. The rats were exposed to the exhalations from a closet, untrapped, and so in a condition to give free egress to the gases from the sewer. I kept them in a box whose lower side, made of a network of metal, closed the aperture of the closet. The guinea-pigs and rabbits were kept in a case whose bottom was also formed of a metal network, under which was placed a vessel in which were excrementitious substances. The animals were fed in the same way as others kept in a normal condition, which were to be inoculated as a control for the proceeding."

Now what are here named as the controlled experiments are those that were made upon animals under ordinary conditions for the purpose of detecting the difference between them and the effects of insanitary conditions.

Another most interesting point which was brought to light by a further set of experiments goes to prove that it is not any one of these gases that appears to be the cause of the susceptibility to disease, nor even artificial combinations of them. Here is a list of the gases and their effects, in which only 3 animals died out of 56 subjected to the treatment, as against 94 out of 121 exposed to the direct emanations from the soil pipe. From this it may be assumed either that there is some poisonous gas that has escaped analysis, or that there is some toxic principle present which is too subtle to be detected by existing methods. Whatever the immediate poison may be, there is no doubt that it exists, that it is dangerous to the lower animals, and much more so to man. It is evident, therefore, that no system of sanitation is complete which does not provide for an absolute exclusion of these gases from our dwellings. The means which are now adopted for this purpose are as follows :—1st, disconnection between drains and sewers, and between waste pipes other than soil pipes and drains ; 2nd, efficient trapping ; and 3rd, efficient through ventilation of all pipes or drains which are used for the conveyance of anything that can lead to the formation of the gases.

No. 3.

Substance experimented with.	Animals under experiment.	Days on which the experiment began.	Days on which typhoid inoculations were made.	Prepared animals.		Animals in control experiment.	
				Inoculated.	Died.	Inoculated.	Died.
Retilindol	Rats	May 24	June 5	1	0	1	0
	,, ...	May 24	June 28	5	0	4	0
Ammoniacal vapours	,, ...	July 7	July 23	4	0	4	0
	,, ...	July 7	July 30	4	0	4	0
Sulphuretted hydrogen	,, ...	July 28	Aug. 11	8	1	4	0
Methyl sulphide ...	,, ...	Aug. 16	Aug. 25	8	0	5	0
Carbonic acid	,, ...	Aug. 29	Sept. 7	5	0	3	0
Carbonic oxide	Guinea pigs	Sept. 13	Sept. 21	4	1	3	0
Retilindol and methyl sulphide	Rats	Sept. 21	Oct. 2	4	0	3	0
Retilindol, methyl sulphide and ammonia	,, ...	Oct. 6	Oct. 15	5	0	3	0
Sulphide of ammonium	,, ...	Sept. 21	Oct. 2	4	1	3	0
Sulphide of ammonium and methyl sulphide	Guinea pigs	Oct. 6	Oct. 15	4	0	3	0

Disconnection of Discharge Pipes from Drains and Sewers.

Although disconnection, as we now understand it, is a very simple affair, and is of itself an enormously important contribution to the production of a sound and healthy drainage system, it has only been in use for a comparatively short time. It is safe, I think, to say that, down to the year 1870, that is, about 26 years ago, disconnection was almost unknown, and was certainly never carried out in the practice either of engineers or architects. I had thought of it independently myself, as no doubt many others had done, but so far as I know the first to introduce it in its present form was Dr. Fergus, of Glasgow, who had an arrangement carried out behind his house which consisted of an accessible half-channel pipe covered at the ground level with a grating, and discharging into an old-fashioned form of trap (*Fig.* 1, *Plate* VII.). That particular arrangement I saw myself. We have various developments of this arrangement in the diagrams, and it is unnecessary to say more with regard to it, as it is now universally used and appreciated, and familiar, I have no doubt, to everyone present (*Fig.* 2, *Plate* VII.). The other form of disconnection is equally well known to you, and consists of discharging waste pipes openly over self-cleansing gullies. This, also, it is unnecessary for me to enlarge upon, but I think it is safe to say that these two simple devices have saved thousands of lives since they were brought into general use.

Traps and Trapping.

Coming now to the subject of trapping, probably the first form of trap used for drains was that known as the "dipstone," which was no more than a catch-pit provided with a tongue dipping into its contents, and the reason for this is to be found in the fact that stoneware pipes are a comparatively recent innovation, having been first made, I believe, about fifty years ago. When they were used it then became practicable to have a trap made of the same material, and the first of these was, no doubt, the running trap, which provided for neither disconnection nor ventilation (*Fig.* 4, *Plate* VII.). We then come to the system of disconnection and trapping used by Dr. Fergus, to which I have already referred, then to a form of trap known as Buchan's, which is still extensively used, and so on with slight changes in form to the present time. *Fig.* 6, *Plate* VII., shows a type of trap with provision for ventilation; *Fig.* 5 a somewhat similar trap fixed without a man-hole for inspection or access, but also provided with an air-let; *Fig.* 7 a form of disconnection known as "Potts'" trap; and *Fig.* 3 an arrangement introduced by Mr. Norman-Shaw, in which the closet discharges untrapped into a hopper-head.

Coming now to the smaller pipes of discharge, we find that trapping has been long adapted as a practical device for preventing the intrusion of gases, and a complete prototype of the most modern form of **S** trap is clearly shown in Alexander Cummings' specification of his water closet in the year 1775.

The **S** trap still survives, and so also does the half **S** trap. Others, including the **D** trap and the bell trap, are fortunately extinct, and are not likely to be revived. After having done incalculable harm by leading to a sense of false and dangerous security, they have gone the way of the pan closet, let us hope for ever. It is important, however, to remember that the most efficient trap in itself may be fixed under conditions that render it quite valueless, for two reasons: 1st, because its contents may be forced out by the air compressed in the pipes connected to it by discharges of water from some other part of the system; and 2nd, by the sucking out of the contents of the trap from the action of a column of falling water. Both these contingencies must be most carefully guarded against, and the means for doing so efficiently is to be found in allowing a free vent for the air in every case, whether it be pressure or suction. This liability to the removal of trap contents should always have weight in estimating the diameter of house drains and soil pipes, because the capacity of a pipe or drain to carry away the whole discharge from a building may be quite sufficient, and yet it may be so full at times that the passage of its contents acts either as a plug in forcing air before it, or drawing it in behind in such a way as to lead to a failure of the traps. In every instance, for the purpose of having them self-cleansing, the pipes should be made as small as possible, so long as they are capable of delivering the maximum amount required of them, but, at the same time, in every case provision should be made by which all pressing or sucking of the air should be avoided at every point.

I have here an illustration of the contents of a trap being forced, and you will notice that this is caused by a descending body of water, which, if it is in any considerable volume, must necessarily force a body of air in front of it. In a well-arranged drain this would have no vent in the direction of the outlet, because the only opening to the outside air should be through a non-return valve for the admission of air for ventilation, which should close so as to prevent the passage of foul air from the drain. The air, compressed by the descending column of water, would therefore have to find relief in the direction of the nearest ventilating shaft, which in most cases ought to be carried clear of all windows and chimneys as high as the ridge of the roof, and this represents a considerable resistance to any sudden movement. It follows, therefore, that the volume of air in the drains and ventilating pipes should be sufficient to allow of its having a certain increment of air suddenly added to it without allowing the pressure at any point to exceed the small resistance afforded by the slight head of water in the seal of the traps most likely to be affected by it. But while this in many cases might be adequate, it is not to be depended upon, and the best remedy is to make the ventilation pipes which are fixed for the prevention of syphoning of such a diameter that they provide ready exit for the air which is forced in front of a descending column of water. It follows that a small ventilating pipe, which might be sufficient to prevent syphonage, may be quite inadequate to prevent the forcing of traps in a high stack of soil pipes.

Coming now to the provision which should be made for the prevention of loss of water seal from suction, it may be generally stated that in every case it should be easier for air to be drawn than water by the descending column, so that the contents in the trap should remain unaffected. Mere ventilation back into the soil pipe is not sufficient when closets are fixed one above the other on the same stack. In all such cases a separate ventilating pipe should be provided to prevent forcing or syphoning of the traps, and this should be of ample capacity and greater than that of the soil pipe when it is a very high one. To show how great the movements of air sometimes are, Mr. Hellyer mentions the case of a soil pipe in which an anemometer registered the passage of 360 feet lineal of air from the discharge of a single valve closet.

Provision for Cleansing and Inspection.

I must now refer shortly to another leading feature of modern drainage, and that is the provision which is made for cleansing and inspection (*Fig.* 2, *Plate* VII.). One cardinal practice should always be adhered to, and that is, that not only should all drains be laid to true and regular falls, but that they should always be constructed in straight lines from point to point, and that all junctions or angles should be made accessible by means of inspection chambers. In fact, every pipe and connection should, if possible, be made accessible throughout. In the case of the Foundling Hospital, I was able to embody this in practice by utilizing the old sewers, which were thoroughly cleansed and white-washed, the new drains being made of cast iron, and laid upon cast-iron chairs along the inverts of the old drains, with channels underneath to take away surface and drip water, and this was separately disconnected from the drain* (*Fig.* 3, *Plate* VI.). It was in doing this that I developed the idea of the cast-iron man-holes, which provide for the means of access in a self-con-

* A similar arrangement was afterwards adopted for the drainage of the Houses of Parliament.

tained form, and of which I have here one or two specimens. They can, of course, be made to meet any possible requirement in the way of branches (*Figs.* 1, 2, 3 and 4, *Plate* V.). One disadvantage of the ordinary brick man-hole is that it retards the passage of the air currents of ventilation through the pipes, that it allows of the constant accumulation of considerable volumes of foul air, and that it is almost as unsuitable as stoneware pipes laid in short lengths to resist any severe test with water. Even if the walls of the man-hole be so well built and rendered with cement that they are water-tight, there still must be points which are liable to leakage where everything depends upon the cement adhering properly to the glazed surfaces of junctions and half-channel pipes. None of these objections occur in the use of cast iron, where everything can be arranged so as to stand any test of water that is ever likely to be applied to it even by the most exacting of inspectors.

I must, before concluding, point out an advantage possessed by cast iron over stoneware drains which is of the greatest importance to any central authority which is responsible for extensive systems of internal sanitation. I refer to its suitability for being delivered *complete* ready for fixing in any situation and at any distance from the place of delivery. All that is necessary is—

(*a*). An accurate drawing to scale of the ground plan of the buildings to be drained.

(*b*). An accurate indication of the position of the latrines, closets, sinks, etc., to be provided for.

(*c*). That the whole system should be put together unfixed and carefully marked before delivery, so that each part can be re-arranged at its destination.

Figs. 12, 13, 14, show a case in point, where drains designed by Mr. Philip Webb and myself were delivered from London and fixed at Middlesborough without a single letter having passed either by way of explanation or correction after they left the hands of the firm who supplied them.*

It is hardly necessary to point out the contrast between such a transaction and the delivery of stoneware pipes, half-channel pipes, gullies, cement, etc., where the whole success of the installation depends upon the skill of the workmen employed in putting them together in the buildings to be dealt with, which may be in some remote locality where skilled labour is unobtainable.

* The firm referred to is the North British Plumbing Company, Limited, of 86, Newman Street, London.

LECTURE III.

In the last lecture we dealt with the methods which should be adopted for preventing the intrusion of gases into dwellings by means of suitable drains and pipes properly trapped, with arrangements for ventilation, so as to avoid the forcing or syphoning out of the trap contents, also means for disconnection, cleansing and inspection. This brings us from the private apparatus of the householder to the provision which has to be made by public bodies for conveying the sewage away.

Where there is ample fall, there can be no doubt as to the general character of the arrangements which should be adopted to effect this object, and when the force of gravity is sufficient to ensure a self-cleansing velocity in the sewers and conduits, it is obviously the one which should be utilized as a matter of course. The shape and capacity of sewers are a question of simple calculation in relation to the work which they may have to perform, and there is no branch of engineering which is more complete, both as regards theory and practice. It often happens, however, that the force of gravity is not available by reason of the situation of the communities whose sewage has to be disposed of, and cases frequently occur in which an engineer has to determine as to whether he shall make use of some more artificial methods for obtaining the proper conditions of removal. When the discharge of sewage takes place into the sea from a seaside town, the margin available from the force of gravity must necessarily be small, at least in the great majority of cases, because those buildings which are situated nearest the level of the highest tides, unless they are dealt with separately, must fix the level of the invert of the lowest sewer. It is in such cases that the engineer should hold himself free to adopt any artificial means of dealing with the flow which will produce the most satisfactory results, and there is no doubt that in many cases great mistakes have been made by looking upon gravity as if it were the only available force. Taking the case of a town two-thirds of which is built upon cliffs or rising ground considerably above the sea level, and one-third of which is built at a level so low, that gravity will not provide for a self-cleansing system of sewers in the lower parts of the town, it follows that the respective merits of the following alternatives have to be considered:—1st. A high-level system with an intercepting sewer worked by gravity and self-cleansing, with a system of artificial delivery for the lower portions of the town. 2nd. A system by which all the sewage of the town gravitates to one point of artificial discharge, the sewers in the lower part of the town being made very deep to provide for a self-cleansing velocity. 3rd. A gravitation system with storage, for discharging at low water. 4th. A system in which mechanical points of discharge are arranged so as to provide the maximum of self-cleansing efficiency at a minimum of cost, taking advantage of gravitation where it is available. Now I think it may safely be stated that the last alternative is the one that is the best, and at the same time it is the one that has been least generally adopted. The practice hitherto has been to utilize the force of gravity under circumstances which render it practically unavailable for self-cleansing velocities, or to utilize it by means of very deep sewers to bring sewage to a single point of mechanical discharge, where many points of discharge would have been more efficient, and more economical as well. As the points we are now dealing with affect the first principles of sewage removal, I shall shortly refer to the available means of mechanical discharge, using the term as opposed to the natural movements obtained from sewers with a self-cleansing inclination. The first method is by having large pumping engines elevating the sewage from a sump. The second is by having several smaller pumping stations, requiring separate motive power and attendance. The third is by having a central station distributing power to subsidiary stations hydraulically. The fourth is a similar arrangement, but worked by compressed air instead of by water. The last system has been fully worked out and developed by Mr. Shone. I cannot do better than describe it in his own words :—

"Shone's Pneumatic Ejector.

"The above figure (*Fig.* 1, *Plate* X.) gives a sectional view of a Shone pneumatic ejector of ordinary construction, suitable for raising water, sewage, sludge, chemicals, and hot fluids of all kinds. Ejectors are made of any size or shape convenient for the special circumstances for which they are required. For sewage, sludge, and pail contents, preference is given to those having the lower portion of hemispherical shape.

"The motive power employed is compressed air, and the action of the apparatus is as follows :—

"The sewage gravitates from the sewers through the inlet pipe A into the ejector, and gradually rises therein until it reaches the underside of the bell D. The air at atmospheric pressure inside this bell is then closed, and the sewage, continuing to rise outside and above the rim of the bell, compresses the enclosed air sufficiently to lift the bell, spindle, etc., which opens the compressed air admission valve E. The compressed air thus automatically admitted into the ejector presses on the surface of the sewage, driving the whole of the contents before it through the bell-mouthed opening at the bottom, and through the outlet pipe B into the iron sewage rising main or high-level gravitating sewer, as the case may be. The sewage can only escape from the ejector by the outlet pipe, as the instant the air pressure is admitted on to the surface of the fluid the valve on the inlet pipe A falls on its seat, and prevents the fluid escaping in that direction. The fluid passes out of the ejector until its level therein reaches the cup C, and, still continuing to lower, leaves the cup full until the weight of the liquid in the portion of cup thus exposed and unsupported by the surrounding water is sufficient to pull down the bell and spindle, thereby reversing the compressed air admission valve, which first cuts off the supply of compressed air to the ejector and then allows the air within the ejector to exhaust down to atmospheric pressure. The outlet valve then falls on its seat, retaining the liquid in the sewage rising main, and the sewage flows into the ejector through the inlet once more, driving the free air before it, through the air valve, as the sewage rises; and so the action goes on as long as there is sewage to flow.

"The positions of the cup and bell floats are so adjusted that the compressed air is not admitted to the ejector until it is full of sewage, and the air is not allowed to exhaust until the ejector is emptied down to the discharge level.

"The compressed air for actuating the ejector is produced at some central station, and conveyed in iron pipes laid under the streets to the several ejector stations."

Any of you who are interested in this most important branch of practical sanitation cannot do better, if opportunity offers, than pay a visit to the outfall works at Isleworth, where you will see a system in constant operation day and night which struck me as one of the most beautiful instances of utilizing the forces of nature to the service of man which modern science and ingenuity has ever devised, and which reflects the greatest credit upon those who carried it out. A still more recent apparatus for lifting sewage is one in which the sewage from a high level, or any fall of water, is utilized for raising sewage from a lower level. Its action depends upon the compression of air in two cylinders, and takes place automatically (*Fig.* 2, *Plate* X.).*

There are so many conditions which require careful consideration in carrying out sewerage operations when the force of gravity is only partially available that every case must be decided upon its own merits, and there are other instances where a divergence of opinion frequently occurs as to whether or not the sewers should take the combined sewage and rainfall of a particular district, or whether there should be a separate system for each. Although the proposition, when put in a general way, seems one that should be easily determined, there are often many points that have to be carefully weighed before a sound conclusion can be arrived at. In large towns, where the horse traffic is heavy, and where the means for removing the excreta are limited, surface water differs little in its character from ordinary sewage. Why, then, it may be asked, should there be two systems of sewerage when one would be equally effective?

On the other hand, it must be remembered that the difficulties and expense of dealing with sewage at its outfall, especially when the towns to be dealt with are inland, is almost directly proportional to its volume, and the reduction of the amount is of the greatest importance in the great majority of cases. If rainfall can be conveyed away separately and delivered in such a state of purity that it can be discharged without treatment, every gallon so delivered will go to a reduction of the cost of treating the discharge from the sewers themselves, and if doing so represents a money-saving which outweighs the cost of a separate system of surface water drainage, then the separate system is justified. But here again every case must be dealt with on its merits.

The Removal of Grease.

One reform, I think, is urgent, and it is that in every community special provision should be made for the collection and removal of grease. The difficulty of disposing of it at present has led engineers to recommend that it should be passed direct into the drains and sewers, where it not only gives rise to foul emanations, which are little affected by flushing, but where it materially adds to the difficulties of final purification. Grease has a totally different

* It is not improbable that turbines driven by electro-motors from a central station may be utilized where the circumstances are favourable.

character from the other components of ordinary sewage, and has this great difference as well—that in the majority of cases it would amply repay the cost of collection. The grease that might be collected from the West End of London would be more than sufficient to lubricate the wheels of every vehicle in the County of Middlesex, and the cost of its purification would be trifling.*

And now, before leaving the subject of sewers and sewage, which I have only been able to deal with in the most general way, there is one cardinal point to be remembered—that whatever the conditions as to fall may be, the sewage should always be delivered so as to give a clear available drop of at least eight feet at the point of discharge for the purposes of treatment and purification, which is the next subject we shall deal with, viz., the fourth and last requirement of good sanitation, which is purifying and utilizing when possible the waste products of the living for the nourishment of vegetation, without injury to health and without creating a nuisance.

Sewage Disposal.

This takes us back to the subject matter of our first lecture, and more especially brings us at once face to face with the question how should the down-grade side of the circle of life, that is, the breaking up of the complex materials of which organic matter is composed, be so conducted and controlled that when the bottom is reached the life process may again be capable of ascending the circle and of re-arranging the old materials with the same infinite elaboration as before. And it is to be remembered that we are not now dealing with the case of a few individuals who are wandering through healthy highlands, where nature unaided plays the part of sanitarian, but with vast accumulations of water-borne wastes, which must be treated continuously if they are to be treated at all.

The problem, on a small scale, may be put in a form that is capable of very accurate expression by again referring to this small phial containing nutritive gelatine, which has remained sterile for about four years with the sole protection of a plug of cotton wool, viz., how are the contents of the flask to be converted by a purely natural process into their simplest elements of nitric acid (HNO_3) phosphoric acid (H_3PO_4), carbonic acid (CO_2), and water (H_2O)

* A good form of grease trap is shown on *Fig.* 2, *Plate* IX., in which there is access to both inlet and outlet pipes, and baffler plates attached to the movable pan, which prevent the passage of the grease, when hot, into the outlet.

It is in these final forms that nature is best able to utilize organic wastes for the nourishment of plants, and it is obvious at the outset that nothing can be gained by keeping it sterile as you now see it, or by rendering it sterile by combination with chemicals.

The methods which have hitherto been employed for the disposal of sewage have not been based so much upon investigations as to the possibilities of purely natural processes as upon more artificial devices, such as deposition of the solid and final purification by chemicals. These are still greatly utilized, and are not only costly, but in the great majority of cases fail to yield satisfactory results. The substance which has been most largely employed has been lime, and from experiments made by the Massachusetts Board of Health it appears that nothing is to be gained by using it to excess, but that, on the contrary, there is a certain quantity which gives the best results in relation to the varying qualities of the sewage to be treated, neither more nor less, and in the case of the particular sewage which was the subject of experiment, 1,800 lbs. per 1,000,000 gallons gave the best results, but that even in the most favourable results as much as one-third of the nitrogenous organic matter remained in the effluent. It is needless to say that this amount is quite sufficient, if it is in a stable condition to begin with, to give rise to secondary fermentation. The result of much experience has led to the use of ferric sulphate, or aluminia sulphate, also copperas, and the Massachusetts experiments went to show that in the case of the first two no lime was necessary, but that it was required in the case of copperas.

In every case in which chemical treatment is employed there is an effort made in the first place to precipitate as much of the organic matter as possible in the form of sludge, which is generally found to be a much less valuable product than at one time was expected, and which generally entails the use of an elaborate apparatus for pressing it into a more solid form.

Purification of Sewage by Biolysis.

I now come to another aspect of the problem of sewage purification with which my name is associated, and it will always be a source of gratification to me that I have been able to make some contributions towards its solution. As the result of experiments which I made upon the sewage from my own house in 1891, it dawned upon me that if nature was capable of dealing with the same total of the waste products of life upon the planet, there was nothing unreasonable in supposing that the same forces, if properly applied, would be capable of dealing with all the organic matter contained in the sludge of sewage, and that if this supposition was correct, then the process of precipitation might be looked upon as one which simply deprived the organisms which nature employed as her scavengers of the food which it was their proper province to devour.

Of the presence of these organisms in the sewage there could be no doubt, as it was only possible to remove them either by large quantities of antiseptic preparations or by sterilization by heat. Even then there were other organisms continually ready to take the place of those which had been destroyed, and, in fact, unless elaborate precautions were taken, which are not possible on a large scale, nature was always prepared to renew her attack by the very same kind of organisms that she had originally employed. If the amount of the organic matter contained in the sewage of a large town seemed to be in excess of the capacity of these natural forces to deal with, that difficulty seemed to disappear in the light of what was already known as to the prodigious and almost incredible capacity of these organisms to increase in numbers, and to encroach upon any amount of food which could possibly be supplied to them. On the one hand, if such a system were to be applied to the sewage of London, 67,583 million gallons would have to be treated every year, and this yielded 2,021,000 tons of sludge in 1893. It seemed impossible to suppose that the whole of this could be subjected to the elaborate process of chemical disruption, to which I gave the name of biolysis, by organisms which, in their simplest forms, would require to number 25,000 to make up a procession one inch in length. On the other hand, Cohn had calculated that a single germ could increase by simple fission at such a rate that, if the conditions were absolutely favourable, their numbers at the end of the third day would reach the prodigious total of 4,772 billions, and that if this were estimated in weight, the mass arising from the single germ would weigh 7,500 tons. Even if their increase fell immeasurably short of the theoretical amount, the presence of the organisms in vast numbers was sufficiently proved from the observations in my own laboratory, seeing that 1 cubic centimètre of the effluent from a "cultivation" tank contained as many as 3,562,000 micro-organisms, so that after all it seemed as if the vast amount of organic matter to be purified had its counterpart in the unlimited forces which nature seemed to have at her command for dealing with it.*

Time, unfortunately, does not admit of my doing more than give a short account of the state of knowledge at the time at which I made my first attempts at the enlistment of Nature's scavengers as the sole agents of purification. In an excellent textbook, which was published as lately as the present year by Professor Henry Robinson, there is an account of everything of any importance that had been done up to date, and it seems strange that among the many engineers and chemists who have devoted years to a study of the subject, no one should have credited nature with the capacity to deal with the whole process unaided by chemicals of any kind. Out of the 182 pages which the textbook I have referred to contains, no fewer than 69 pages, or more than one-third of the whole, is taken up with the subject of precipitation, and a description of its application to the sewage treatment of a number of typical towns Without going into details as to how the precipitation of sludge is obtained in every case, it is enough to point out: 1st, that the results are obtained at an enormous cost; 2nd, that the material which should be utilized is in many cases, such as London, absolutely thrown away by being carried out to sea; 3rd, that from a return which was made to the Local Government Board in 1894, out of 234 places, it appeared that only 30 obtained anything for the sludge, the amount varying from 1s. to 2s. 6d. per ton, and only one process, so far as I know, has seriously dealt with the question from the point of view of a good manurial result.

You can understand, then, that there was nothing to guide me either in the prevailing practice, or in the state of knowledge at the time, and that, beyond the conviction that nature was to be trusted to complete her own methods, I began by working very much in the dark. Anything that was known in this country at the time had reference to the action of certain organisms in the soil, and this had only a remote bearing on the purification of organic matter in large volumes of liquid, except in relation to its disposal on land. After I had been at work some time, my views received remarkable confirmation from a long series of valuable experiments which had been commenced by the Massachusetts Board of Health at Lawrence in the year 1888, the latest results published having been brought

* M. Miquel gives the number of organisms found in Paris sewage at 13,800,000 per cubic centimètre.

down to 1893. Those which bore directly on what I was aiming at were obtained by passing greatly diluted sewage in thin films over the surfaces of stones, in contact with air, causing as much as 97 per cent. of the organic nitrogenous matter—a large part of which was in solution—as well as 99 per cent. of the bacteria, to be removed. The other experiments referred to the effect produced by filtering downwards through variously arranged layers of coarse and fine sand, gravel, loam, soil, etc., the whole investigation being carried out by bacteriological as well as chemical methods, which proved the dependence of the one upon the other. By these purely natural processes, acting under favourable conditions as to air and temperature, as high a rate of efficiency was reached as 97 per cent., measured by the removal of albuminoid ammonia. But while these experiments may justly be spoken of as invaluable, they did not touch the all-important question of how precipitation could be avoided, because a strong sewage would at once clog the filters, and a greatly diluted sewage was not what had to be dealt with in practice, at least in this country.

The experiments of the Massachusetts Board were developed in the direction of artificial supplies of air to the filters by Mr. G. E. Waring, junr., in America in 1894, and Mr. Lowcock in England in 1893. In both cases, while the aim they had in common was to develop bacteriological action, there were arrangements in the first apparatus for straining back the solids, by means of "aprons" and straining tanks, passing the effluent afterwards through filters, which are artificially ærated by machinery.

It was found that the aprons, on having the stones which they contained turned over, and the screening tanks, when they were emptied, were subject to a self-cleansing process, inasmuch as the solid organic matter which was entangled in them became broken up in contact with the air, so that they could be used over again. In Mr. Lowcock's apparatus provision was made for the precipitation of the solid matter by chemicals before treatment in the artificially ærated filters.*

My experiments, which were commenced in 1891, differed from all those I have referred to, inasmuch that I recognized at a very early

* It is unfortunate that Mr. Dibdin, the chemist, and Mr. Binnie, the engineer to the London County Council, when they carried out their praiseworthy experiments upon the bacteriological filtration of sewage at Barking, did not round off their work by making experiments upon the preliminary process of liquifaction, and that all their results should have been obtained after the expensive and unnecessary process of chemical treatment.

period that the process should be broken up into two parts—the first providing for the liquifaction of the organic matter by the common micro-organisms of putrefaction, and the second for the mineralization of the products of the first process by the organisms of nitrification. Although working somewhat in the dark, as I have said, I hit upon an arrangement which provided conditions that seemed to run parallel, as it were, with the experience obtained in the laboratory. When nutrient gelatine is inoculated at favourable temperatures by a liquifying organism, they increase with enormous rapidity during the first three days, attacking the nitrogenous contents of the vessel containing them with the utmost avidity. Afterwards, their activity is greatly diminished, and they decrease in numbers, the whole process being finally arrested. The cause for this is found in the unfavourable environment which arises from them being exposed to the influence of their own products. It appeared, therefore, that two conditions were necessary in order to take advantage of such natural processes: first, that the food should be supplied in as fresh a state as possible, without any previous fermentation; second, that the products of their life processes should be continually removed, leaving the organisms free to move in the direction of the food supply. Here there is a drawing of the original apparatus which I employed, and which I am still using with slight modifications for the first process of liquifaction. The sewage flows first downward into a channel, which the Germans have since called a "restricting chamber," and then upwards through a grating among flints, which provide permanent surfaces for the propagation of the organisms, and it will be seen at a glance that this very simple arrangement provides for the necessary conditions of fresh food, and removal of the products of the life processes of the organisms (*Plate* XI.).

The effluent obtained from these "cultivation" tanks was in many respects peculiar, and could not be judged of by ordinary chemical processes. The reason for this is obvious when it is considered that the organic matter held in solution, and practically there is no suspended matter at all, is in the unstable condition between the organic and the inorganic state, and of this ordinary analytic methods takes no cognizance. The important question as to what happens when further favourable conditions occurred for breaking up the unstable compounds has been equally ignored. And there is no doubt that the failure of the chemist to recognize or estimate that qualifying condition has greatly retarded the development of the system.

As the result of the knowledge which has been becoming more and more available since these early experiments were commenced, there is now a general acceptance of the principles which underlie this solution of the long unsolved sewage problem, and the somewhat grotesque condition of things has arisen in which those who scoffed at the proposal as ridiculous are now rushing in to claim that they were the first to realize it, and to put it into practice. Now that ignorance is no longer likely to stand in the way of progress, one can bestow a sort of benevolent pity upon a little town in Northamptonshire, where, after having adopted the system and obtained the most excellent results, they threw every obstacle in the way of its success.

I shall now quote *in extenso* a summary by Dr. Frankland of the work done in the laboratory of the Rivers Pollution Commission, which, while it fails to recognize clearly the necessary cycle which must occur in a purely biological process, at the same time not only indicates it, but states the relative difficulties of the different stages in the plainest possible manner. He says :—" All classes of processes are to a great extent successful in removing polluting organic matter in suspension. As might be expected, the filtration processes are in this respect the best, irrigation ranks next, while chemical processes are somewhat less efficient for the removal of suspended organic matter. But the getting rid of suspended matters is a simple problem compared with the removal of organic matters in solution. It is here that the different processes experience the most severe trial, and it is on the application of this test that the great superiority of downward intermittent filtration and of irrigation over upward filtration and the chemical methods of treatment becomes strikingly apparent. Thus, in round numbers, it may be said that, on the average, the processes of downward intermittent filtration and irrigation remove from the soluble constituents of the sewage twice as much polluting matter as that got rid of by the processes of chemical treatment and of upward filtration." There is here no reference to the work of micro-organisms, and the question to be answered is as to whether these, under favourable conditions, are capable of carrying on the complete process of purification from the crude sewage, with all its suspended impurities, to the production of an effluent which is altogether innocuous. Now there can be no doubt that this question can be answered in the affirmative. In the "cultivation tank," which I have explained to you, the whole organic matter contained even in the strongest sewage, can be thrown into solution with the exception of a small inert residuum which is almost incapable of analysis, and which seems to be of the nature of peat or humus. But these same "cultivation tanks," when they are filled with other surfaces, such as fine clinker, or coke breeze, though they are still the same in character as those containing flints, can be so duplicated or grouped that practically any standard of purity can be obtained from them ; all that is required is that they should be constantly ærated and rested. During the process of æration the adherent organic matter is dissipated, and when re-charged with the effluent from the first stage they are again capable of carrying on their functions without any apparent falling off in their efficiency. My experience has been that they improve in their action from year to year as organisms continue to survive and flourish which are specially fitted for the work they have to do. The questions that remains till to be solved are as to the best methods for controlling and expediting these beneficent operations of nature. The system will not differ from other systems which are in their infancy, in so far that extending knowledge will lead to the development of improvements. My own belief is that the simple cycle which is represented by liquifaction first and nitrification afterwards will be greatly elaborated in detail, and that we shall have several well-defined stages, some mixed, some anærobic, and others highly ærobic in their characters, with pure, or at least highly differentiated, cultivations of special organisms used during the process. Meantime it is satisfactory to know that we have a method which costs nothing for working it ready to our hands to break up the organic matter without the use of chemicals, and to prepare it for the food of plants without the expense and trouble and failure attending the application of crude sewage to the land, and also a method which can be so duplicated or grouped as to bring about an almost complete return of the organic matter to its original inorganic condition.

PAPER VI.

BRIDGING IN THE PENINSULAR WAR.

THE following account of Bridging in the Peninsular War is taken from a MS. book written by the late Captain George Innis Perry West, R.E., and the circumstances under which we have been able to produce the article are explained in the letter from Mr. Slade. To the latter gentleman the Corps is indebted for the restoration of so valuable a relic.

ROYAL COLONIAL INSTITUTE,
NORTHUMBERLAND AVENUE, LONDON, W.C.
5th October, 1895.

MEMORANDUM.

This book has been in the possession of myself or family since the death of my father, the late Captain Henry Slade, R.A., who died at Up Park Camp, Jamaica, in May, 1841.

It came into his care as part of "the effects" of Captain George Innis Perry West, Royal Engineers, whose executor he was; and on my father's death remained with his books, papers, etc., till about a year ago. When arranging these, and handing most of them over to the Royal Artillery Institution, Woolwich (some others were accepted by the Trustees of the British Museum), I discovered this book certainly was not one of my father's, and put it on one side for further inquiry.

My father and Captain West were at the R.M.A. at the same time, about 1808—1810, and subsequently served together in the later part of the Peninsular War, up to the battle of Toulouse.

They were then ordered to America, Captain West, I believe, to New Orleans, and my father to Canada.

Captain West was certainly at Quebec in 1824, and was lost with his son, and I believe all hands, in a shipwreck off the coast of Honduras about 1833.

Captain West was employed at the building of the citadel at Quebec, as appears from another book, now at the R.A. Institution, Woolwich; one end contains his notes and calculations, some of which are in Greek characters. Great part of the book being blank, my father used it for what proved to be his last journal; this being of some regimental interest, I felt the R.A. ought to have it.

A near relative of my father's, General William Slade, Royal Engineers, had a command at Chatham many years ago, before the Crimean War, and this is an additional inducement to me to return the book to its proper home.

HENRY G. SLADE, F.R.C.I.

IN April, 1812, Lieut.-Colonel Sturgeon was sent from Fuente Guinaldo to Badajos and Elvas to prepare a net of ropes to cross the fracture in the Roman Bridge across the Tagus at Alcantara, the following material being provided:—

4 beams of poplar, each 30 feet long, 12″ × 8″.
8 " " 20 " 6 inches square.
48 joists, each 12 feet long, 3″ × 5″.
120 " " " $1\frac{1}{2}$″ × 5″.
100 $\frac{1}{2}$-inch screw bolts, each 10 feet long.
100 $1\frac{1}{2}$-inch plank, each 12 feet long, 1 foot wide.
50 2-inch plank for the ends, same dimensions.
10 triple blocks, sheeves, 12 inches diameter, brass cogged and iron pinned.
10 double blocks, sheeves, 12 inches diameter, brass cogged and iron pinned.
10 double blocks, sheeves, 6 inches diameter, for working tackles and guys.
10 single blocks, sheeves, 6 inches diameter, for working tackles and guys.
450 fathoms $6\frac{1}{2}$ rope for bridge bearers, etc.
200 fathoms $4\frac{1}{2}$ rope for falls for bridge tackles.
200 fathoms $2\frac{1}{2}$ rope for working tackles and guys.
100 fathoms $4\frac{1}{2}$ rope for straps round the beams.
1000 fathoms 3 and 4 yarn spun yarn.
140 yards strong tarred canvas.
5 cwt. bar iron for cramps and bolts.
200 lbs. lead.

Tar, rosin, grease, marling spikes, fids, old canvas for parcelling, salvagee straps, tail tackles, twine needles, a portable forge, blacksmith's, mason's and carpenter's tools, drills, hammers, scrapers and needles, two pontoon carriages.

4 crabs or small capstans.

30 common cars.

6 Galera cars.

The Galera is a particular description of light car drawn by four mules, and used in Spain for expeditious travelling; it has a cover of canvas to defend the people and goods from the heat of the sun.

The pontoon house at Elvas being selected to prepare the net-work, the two beams AB were placed on stools 4 feet high, at the distance of 90 feet asunder (breadth of the gap to be bridged and secured to the side and end walls of the house by braces and tackles), to prevent their approximating by the strain of the ropes (*Figs.* 1 and 2, *Plate* I.).

The $6\frac{1}{2}$-inch rope was then stretched round them to an equal strain by the working tackles—18 lengths formed the bridge, placed 1 foot asunder from centre to centre of the ropes—the eight pieces of 6 inches square being notched thus  and the notches being burnt with the arm of an iron axletree made hot, to prevent their chafing the ropes, were then laid on the net-work (each notch receiving a rope) at equal distances (see 1, 2, 3, 4, 5, etc.), and there lashed on 4-yarn spun yarn.

The sleepers were then prepared in chains as in *Fig.* 1, and the rope being netted as on the sketch, these chains of sleepers were laid longitudinally from end beam to end beam, the joints resting on the transverse beams 1, 2, 3, 4, 5, 6, 7, 8, and the ends were lashed to the great end beams AB. The planks were prepared by jointing, cutting to a length and boring a $\frac{1}{2}$-inch hole in the end of each to pass a ratling to secure them to the sleepers and to each other.

The whole being to be packed up for transportation, the great net beams and transverse bearers were rolled up and put on one of the pontoon carriages, and the whole apparatus was transported to Alcantara.

Whilst these preparations were making at Elvas, an officer was left at Alcantara to prepare the edges of the fractured part and to cut channels or grooves in the masonry to receive the purchases. The first process on the spot was to stretch four strong ropes from side to side, extending from the beams C to D (*Fig.* 1, *Plate* I.) as conductors to pass the great net over; this done, the rest of the work was completed without difficulty, as on the sketch (*Figs.* 1 and 2, *Plate* I.).

A similar bridge was made in the New Museum at Madrid, and transported to Almaraz, where it was laid across the gap, 143 feet wide, in the stone bridge across the Tagus.

On the 16th July, 1809, Sir A. Wellesley ordered the two companies from Placentia to the river Zeitar, to make a bridge to cross the infantry of his army on the 18th. The profile of the river was found as on the other side (*Fig.* 4, *Plate* I.).

The only material at hand was the timber of a large venta, at about half a mile from the place. Early on the morning of the 17th this building was unroofed, and the timber as follows was produced :—6 beams of dry fir, each about 20 feet long and 2 feet square, and from 300 to 400 rafters about 10 feet long, and 4 inches by 6 inches scantling, 6 large doors and 200 running feet of manger.

Of the six large beams a raft B (*Fig.* 5, *Plate* I.) was made by boring holes through the centre of each towards the one end and passing a rope through them. This raft was placed in the deepest part of the stream, with the bored ends of the beams up the river. One end of this rope was made fast to a tree on the river side, and the other to a stake driven fast into the sand on the shoal of the other side. A working party of 500 men, with saws and axes, was sent to a distance of three miles to procure young pines to make the stakes and caps C, and the bearers E, F, G, H, I, K, L (*Fig.* 4, *Plate* I.), in number 20, each from 25 to 30 feet long and from 6 to 10 inches diameter, with ribbons to keep down the plank, made of the same kind of pieces split thus ⊖ and tied on each of the trestle heads. The rafters, doors and mangers were found sufficient for planking, but as they were too thick for the nails we had, it was necessary to secure them on the bearers by the ribbons as above, laid along the cut ends and tied with willow twigs to the caps of the stakes; a stool was made for the men who drove the stakes to stand on whilst so employed—large wooden mallets made on the spot were used for that purpose (*Figs.* 4 and 5).

This bridge was only for immediate use, and not to be kept up after the troops passed.

In the autumn of 1811, Sir James Leith ordered a bridge to be thrown across the river at Thomar, to facilitate the communications of his corps. The water was found about five feet deep throughout.

Eight stools were made, and of a large quantity of young straight pines growing on the spot a sufficient number was felled to cover the whole laid lengthways and quite close to each other; these were covered with a sufficiency of heath and young branches, over which was laid some earth and gravel (*Fig.* 3).

A flying bridge was laid on the Tagus at Villa Velha on two country boats. A strong rope was stretched across the river to pass this bridge. Twelve seamen were constantly on duty to pull it backwards and forwards. A rope with a large hoop running on it stretched across was kept constantly fixed to this bridge lest the strength of the current should force the men to let go the rope in hauling across (*Fig.* 6, *Plate* I.).

A scaffold was fixed on each side for the carriages and horses to go off and on the bridge; a good railing was placed all round to prevent the cattle from slipping off it. In laying this, as well as all other floating bridges, the baulks or bearers should cross entirely one of the boats and rest on the gunwale of the other (see letters *a*, *b*, *c*, *d*, *e*, *Fig.* 6, *Plate* I.), for the bolts or lashings to secure these bearers together.

An entire bridge of country boats was laid over this place afterwards, as was another at Abrantes, and also one across the Zezere at Punhete.

At Villa Velha 25 boats were used, and at Abrantes, where the river is wider, 57 boats.

Pontoons such as are used in the British service are only useful where the water is smooth and the stream not above three miles per hour.

One of these, on the Guadiana near Badajos, sank during the siege of that place and occasioned a great deal of inconvenience; another was placed by Lieut. Piper, R.E., on the Tagus at Almarar to pass the army of General Hill at the time of the siege of Burjos. It was constantly obliged to be removed on the least increase of the river, and could not be re-placed until the water subsided.

If these tin pontoons were made in the shape of boats instead of square boxes, they might be as easily carried and would be infinitely more useful.

At Puente Murcella timber of a sufficient length could not be got there, and a bridge was made as follows at some distance above (*Fig.* 7, *Plate* I.).

The stream was too rapid and the water too deep to admit of anything being fixed in the river; the left bank was rocky and nearly level with the water; the right was bounded by a stone wall or wharf about 5 feet higher than the water. A working party of 200 men was immediately sent into the village to collect all kinds of dry timber to make a raft.

A sufficient quantity being collected, it was formed on the bank at A (*Fig.* 7, *Plate* I.). Whilst the timber was collecting two ring-bolts were let into the rocks at D and C (*Fig.* 7. *Plate* I.), and six pine trees of about 60 feet long were felled and brought to the spot by the marauders who accompanied the army, and who were seized on and compelled to perform this service. The raft being ready, one of these trees was laid on it and well secured by spikes and cords. A hole was bored in the other end of the tree and it was secured by a heel rope to the ring-bolt at D. Bearers were laid under the raft while it was constructing to launch it, which was done, and a strong party held on the rope EF (*Fig.* 7, *Plate* I.), easing it down the stream to G (*Fig.* 7, *Plate* I.), the place proposed for the bridge.

The rope was then secured to the ring-bolt at C *Fig.* 7, *Plate* I.), and two additional turns were taken round the tree and through the bolt to secure it against the force of the current. A firm footing being thus secured in the middle of the river, a second tree was prepared by boring a hole in its end, it was then slipped along the first beam and secured by a heel-rope to it at G (*Fig.* 7, *Plate* I.); a large cask was procured from the village and well lashed under the end of it. The tree and cask were then launched into the stream and shoved out by poles and boat-hooks from I to K (*Fig.* 7, *Plate* I.), when, being caught by the stream, it was gently and carefully eased down by the rope LM (*Fig.* 7, *Plate* I.) to the situation O (*Fig.* 7, *Plate* I.) against the wall. About 30 men were then sent across this tree, and, by the help of a small tackle fixed to a post on the wharf, hoisted up the cask and the end of the tree on the wall; two other trees were immediately laid parallel to the others, and the whole planked over with doors, chests and such other articles as had been collecting during the time the work was going on.

Crowbars, pickaxes or any pieces of iron let into stones or rocks by a drill will answer the same purpose as ring-bolts if they are not at hand, or the rope may be secured by a portion of rock, or tree, etc., near the place.

N.B.—If the raft sinks much in the river a stool had better be placed on it under the ends of the trees.

In the winter of 1811 his Lordship directed Lieut.-Colonel Sturgeon to prepare in the arsenal at Almeida a bridge of chevalets to cross any of the neighbouring rivers. A sufficient quantity was prepared for a breadth of 500 feet, and of such a construction as to withstand the winter torrents that during sudden thaws sometimes raise these rivers to a very great height. As soon as the whole could be got ready, viz. :—

30 chevalets.
500 feet (running) plank, each 14 feet long.
160 joists, each 18 feet long, 5″ × 10″.
30 piles and piling machine on wheels, to work in the water.
180 fathoms of strong chains.
3000 6-inch spikes.
6000 2-inch nails for the casing.
Hawsers, tackles, etc., etc.

His Lordship ordered that every article should be transported with the utmost possible despatch to the situation he had chosen as above, and to be placed without a moment's delay (*Figs.* 8 and 10, *Plate* I.).

As soon as everything was got ready, a row of piles was driven into the river about three fathoms above the bridge, one opposite each chevalet, and a chain being passed round each pile it was secured to the framework so as to prevent the whole from floating away in event of the river rising over the top of the bridge, which was 12 feet higher than the usual surface of the water.

Early on the morning of the 3rd day of the battle of Fuentes de Honor, the two companies of the Royal Staff Corps (then with the army) were sent to the neighbourhood of the Puente de Pinhel, on the Coa (which had been destroyed by the enemy in their retreat from Portugal), to make as many communications as possible across the river, in order to pass what portion of the army might be thought necessary in the event of its being unable to continue to cover the blockade of Almeida. On their arrival at the spot it was found impracticable to repair the stone bridge from the shattered state of the remaining part of the piers, and almost total want of materials within any reasonable distance; six poplars and some large elms that grew on the bank about two miles upwards were all that could be procured. These were immediately felled, and with great difficulty floated down the river to two places that had been fixed on to attempt making temporary bridges; both these were in situations where the river narrowed, forming rapids so deep and strong that no hold could be got of the bottom. Each of these places was from 60 to 70 feet wide, but as both bridges were made similar, I shall only describe one.

The farthest side of the river could not be got at by any means in our power, it being then a considerable flood.

The profile of the bank next us was the strong line from A to B (*Fig.* 9, *Plate* I.) in solid granite rock. It was immediately altered to CD by cutting a notch at D about 8 feet long horizontally, one foot high and about the same depth, and raising the space to C with dry masonry coped by a beam of timber on the extreme edge; meanwhile a road was made along the face of the rock from A to B (*Fig.* 9).

The two trees CD were then placed as on the figure with their large ends inserted in the notch above mentioned, and by the help of levers and crow-bars were moved along to EF (*Fig.* 9, *Plate* I.) (*i.e.*, the small ends of them), the other ends still continuing in the notch. Handspikes were then lashed on these trees at certain distances to enable men to go out on the ends and push across to the opposite bank two light poles represented by the dotted lines HI (*Fig.* 9, *Plate* I.), across which poles some men were sent, and having thus reached the opposite bank the rest of the work was soon completed.

Bridge Across the Adour (*Fig.* 1, *Plate* II.).

On the 8th February, 1814, the Marquis of Wellington determined on constructing a floating bridge across the Adour below the fortress of Bayonne, with a boom to protect it from any hulks or fire vessels that the enemy might drift down the stream with a view to destroy it.

This bridge was to be placed 2½ miles below the wooden bridge which connects the town with the citadel (and is the same over which the great Chaussée to Madrid passes), and 1½ miles from the confluence of the Adour with the sea, as previously reconnoitred.

The magnitude of the river, the strength of the current (it being the season of the year when the mountain floods were expected) and the occasional effects of particular winds on the surface of the water, rendered it unsafe to trust to the common pontoons attached to the army, even if a sufficient quantity could have been spared from other services. His Lordship therefore decided upon having Chasse Marées, a species of coasting vessels used on the shores of the

Bay cf Biscay, from 20 to 40 tons burthen, and measuring generally about 50 feet in length on deck and from 12 to 15 feet on the beam. 48 of these vessels were immediately taken up in the ports of St. Jean de Luz, Socoa and Passages. They were collected at Socoa and loaded each with 48 3-inch plank, each 12 feet long and 1 foot wide, 2 handsaws, 2 axes and 2 skeins of line for lashing on the planks, one sleeper, 10 inches square and notched.

Two men of the Corps of Royal Sappers & Miners were put on board each for the purpose of cutting away the waist-boards level with the decks the moment the vessels arrived at their stations in the Adour, in order that there might be no delay in stretching the cables, as soon after the vessels were moored in their places as possible.

In consequence of the difficulty in procuring in any reasonable time in the vicinity of St. Jean de Luz a sufficient quantity of baulks to answer as bearers between the boats, his lordship determined, on the suggestion of Lieut.-Colonel Sturgeon, to use 13-inch cables stretched tight by tackles and capstans and resting on the decks of the vessels, which were to be placed 40 feet from centre to centre in a line across the river. These cables were to be five in number, and placed at the distance of 2½ feet from each other, being secured equidistant by lashings in the notches of the aforesaid sleepers, one of which was placed fore and aft on the deck of each of the vessels.

Sixteen 13-inch cables were procured, some being taken by the Admiral from the transports, and some purchased at St. Jean de Luz. These were put on board those of the Chasse Marées that were intended to be placed in the centre of the bridge, and so coiled that they could be handed out to both sides of the river at the same time.

The river was bounded on both sides by perpendicular stone walls 14 feet high and the same thickness; that on the left bank was backed by sand level to its surface; whilst the ground behind the wall on the right bank was 12 feet lower than the top of the wall, and covered at high tide by 7 feet of water; the rise of the water at spring tides was 14 feet perpendicular. Cables were also preferred to baulks, because, from their elasticity, they were better calculated to meet the rise and fall of the water, as well as the motion of its surface, and, besides, in the event of the enemy's being able to force or break the boom by his hulks, fire vessels, or other means, floated down the stream for that purpose, these five cables would have proved an additional obstacle and most likely would have arrested their progress until the store and provision ships that were anchored below the bridge could, by cutting or slipping their cables, be got out of the way. It was determined that the ends of the cables should be secured on the right bank by affixing to cables an 18-pounder iron gun, and throwing them over the back of the wall into the mud, serving that part of the cables which rested on the masonry with raw bullock hides to prevent their chafing, and on the left bank to capstans and gin tackles, fixed to a frame of timber prepared on purpose, laid on the sand behind the wall, three feet lower down than the top of the masonry, and loaded in the rear by a transverse of sandbags.

The Chasse Marées were told off into five divisions, commanded by Engineer officers, one of whom was entrusted with hoisting the guns over the wall on the right bank and securing the ends of the cables to them; another officer was charged with securing and tightening the purchases on the left bank.

Lieut.-Colonel Elphinstone, the Commanding Engineer, proceeded with Sir John Hope's column to determine the precise place where the bridge was to be laid across, having in view to hide it as much as possible from the place, allowing at the same time sufficient room for the anchorage of from 200 to 300 vessels between it and the river's mouth.

A flexible boom was prepared at the same time, under the direction and with the assistance of Admiral Penrose, for the protection of this bridge. It consisted of masts from 50 feet to 100 feet long and from 1 foot to 2 feet in diameter, placing the strongest in the front line; these were anchored each individually by the centre, those in the first line being anchored up the river stream and those in the rear line having their anchors down to meet the flood tide. The masts in the first line were placed 20 feet asunder, and connected with chains as well with each other as with those in the rear line, making the masts in the one line cover the intervals in the other These lines were to be 24 feet asunder, and the chains were to be allowed to hang slack so as to be 1½ feet below the surface of the water. This was calculated to give that elasticity so necessary to resist the violence of a first shock. Two strong 13-inch cables were at the same time stretched along the whole line of masts and set as tight as possible, lashing them to both ends of each mast. Four gunboats were placed in advance of this boom to assist in its protection, and on each bank of the river was placed a battery of three travelling 18-pounders, whilst light boats were constantly kept in readiness with graplings to meet and anchor anything that might be drifted down the stream before it reached the boom.

On the evening of the 22nd, the whole being ready, went to sea under convoy of the *Porcupine*, frigate, Admiral Penrose's flagship, *Lyra*, brig-of-war, Captain O'Reilly, and five gunboats. The wind during the night was fresh but contrary; next day light and variable; on the 24th, in the afternoon, 34 of these vessels entered the Adour. One foundered on the bar, one and a transport were driven on shore on the beach, and twelve were forced back to St. Jean de Luz; two transports, carrying the boom, entered at the same time, and a sloop similarly employed was driven on shore on the beach; four of the five gunboats entered, and the other was driven on shore, and finally dashed to pieces. This diminution of means, particularly the Chasse Marées, in which were the three officers, three of the cables and the Commissary of Provisions, with his stores, as also one with two cables, rendered a removal of cables and a different arrangement necessary, which added to the difficulty of mooring the vessels except at slack tide, occupied the whole of the days of the 25th and 26th, on the evening of which last day it was completed.

Of the 34 vessels which entered 25 were made use of for the bridge, 4 were held in reserve to re-place any that might be destroyed by the enemy; and 5 were given to the Commissariat to go to Passages for stores.

After the suspension of hostilities, the booms laid down above the bridge for its protection were taken up and placed between the vessels as bearers; their lengths made it practicable to remove six vessels from the bridge, which six, with the four in reserve, were given over to the Ordnance and Commissariat for other services. On the 12th May this bridge was broken up.

Hire of the 25 boats which originally entered the Adour, £123 8s. 6d. per day; hire of 19 vessels, to which number it was reduced, £72 18s. 0d. per day; besides the above, 200 rations per diem were issued to the crews of those vessels during the whole period.

The pontoons usually made use of are of the following dimen sions:—

Length of gunnel, 21 feet.
,, at bottom, 17 feet.
Breadth, 4 feet 10 inches.
Depth, 2 feet 3 inches.

Distance between the inner and outer partitions at the sides: at top, 6 inches; bottom, 1 foot 2 inches.

Distance from ends to the breast rings, 3 feet.

Weight capable of bearing, 103 cwt.

Weight the sides will bear when the centre is filled with water, 29 cwt.

The end-rings should be placed at each corner of the pontoon.

From end to the gunnel socket, 1 foot 1 inch.

Thickness of gunnel, 6 inches.

Cross pieces and inner framing about 1 inch square, and 1 foot distance between each.

The inner and outer partitions have a waterproof division, distance 1 foot from each other.

Weight of the pontoon, 11 cwt. 2 qrs.

" " " complete with carriage, 36 cwt.

Equipage for one Pontoon.

6 baulks, 5″ × 4″, 22 feet 8 inches long.

6 chesses, 2′ 9″ × $1\frac{1}{2}$″, 12 feet long.

1 gang-board, 12 inches wide and 2 inches thick.

1 anchor, 3 feet 11 inches long, 1 qr. 27 lbs. weight.

1 cable, 3-inch rope, 180 feet long.

1 breast line, $2\frac{1}{2}$-inch rope.

5 ledges, $5\frac{1}{2}$ inches wide, $1\frac{1}{2}$ inches thick.

1 divider, 1 gauge-board, 1 boat-hook, 2 oars, 6 rack-lashings, 1 park picket.

Method of Laying a Pontoon Bridge (*Fig.* 2, *Plate* II.).

The boat destined to take the sheer-lines over the river must, if the stream is rapid, be launched above the place where the bridge is to be laid. These sheer-lines are made fast to pickets, or whatever is found most convenient, 25 feet apart one from the other.

The pontoons are moored to the sheer-lines by end lashings, which can be tightened or slackened at pleasure. The cable is passed through the end rings, and the end made fast by two half-hitches, so as to give an equal strain on both rings.

The pontoons are laid at proper distances by applying the dividers to both ends until the breast lines are made fast, which is done by hitching the one end to the ring of the pontoon, then passing the other end through the two rings of the next pontoon and hitching it to the opposite ring of the first pontoon.

The baulks are then laid six and six, and gauged at both ends by the gauge-board.

They may be either placed with double bearings, which is when the ends of both baulks pass entirely over the pontoons and rest on the opposite sides, which must be the case when the pontoons are in open order from 6 feet to 10 feet; or with single bearings, which is said to be the case when the ends of the baulks bear on the same gunnel, and only one passes over the pontoon.

When the baulks are properly arranged, one of the outer ledges of the chess will fit close to a baulk on one side and leave a space of a baulk on the other; covering the next set, the chess must be kept close to the baulk on the opposite side, which will keep them in a right line.

After the chesses are laid on, the gang-boards, which have served all along as communications between the pontoons, are lashed to the end of the chesses by the rack lashings; the bridge is then completed.

To form a Cut in a Pontoon Bridge.

Cuts are required in bridges when the navigation of the river must not be impeded.

A raft is formed the breadth of the cut, and the baulks are so laid as to fit in with the ends of the cut; two or three feet must be left between the pontoons at the fixed end and moveable part. Short baulks of 4 or 5 feet long are bolted on the regular baulks of the latter to cover the gap between them and the bridge. These small baulks, when the raft is to move, may be lifted up, the bolts acting as pivots.

The sheer-line must then be slackened so as to allow the vessel to pass over it, and the raft having ropes fastened to it so as to draw it behind the bridge. Care must be taken to anchor the end pontoons on each side very firmly.

Barrel Bridges.

The best barrels for the purpose are the longest. Seven is the usual number for each pier.

To construct which the barrels are arranged in a line, and two gunnel pieces, about 5 inches square and of sufficient length to project 2 or 3 feet at each side beyond the tier of casks, are placed on them at the distance of about 4 inches from the ends; two cords, $2\frac{1}{2}$ inches thick and $6\frac{1}{2}$ fathoms long, fastened at each end to the gunnel-piece, are then passed underneath the casks and secured by lashings between each.

Holes are made at the ends of each gunnel-piece to lash the end-lines to.

When the barrel piers are constructed they are made use of as pontoons.

The following articles are required for each pier:—

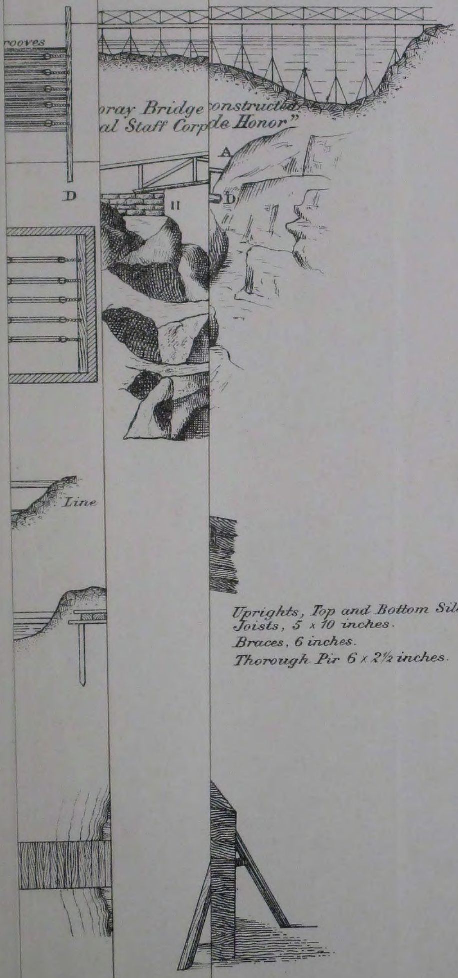
2 pieces of timber, 21 feet by 5 inches square, for gunnel pieces.

2 slings of $2\frac{1}{2}$-inch rope, each $6\frac{1}{2}$ fathoms long.

12 sling lashings, each $2\frac{1}{2}$ fathoms long.

This is in addition to what is required in common with a pontoon.

PLATE I.



rooves
oray Bridge constructed
al Staff Corp de Honor"
A
D
D
II
Line
Uprights, Top and Bottom Sill 8 in. sq.r
Joists, 5 x 10 inches.
Braces, 6 inches.
Thorough Pir 6 x 2½ inches.

PAPER VII.

WATER SUPPLY AND COLLATERAL WORKS.

By J. H. T. Tudsbery, Esq., D.Sc., M.Inst.C.E.

A Lecture Delivered at the S.M.E. on 28th March, 1897.

It is obviously impossible in the space of an hour to present anything approaching a comprehensive treatment of the characteristics, let alone the methods of construction, of the wide range of works and structures incidental to systems of water supply. All I can venture to attempt in the time at disposal is a sketch of some of the principal considerations that are involved in laying out such works.

Passing by the direct interception of rainfall by artificial water sheds (for example, on the roofs of houses), and artificial evaporation and condensation from sea water, which methods are of limited application, water supply is derived from two main sources—wells and streams. Nor are these sources of subterranean and surface waters respectively essentially different in kind; a well merely affords access to that body of water which is percolating the earth, and, under the action of gravity, is pursuing the easiest route from the surface upon which it has fallen as rain to the ocean whence it was originally derived. To appreciate properly the conditions under which ordinary wells may be used as sources of water supply, it must be realized that there is always a vast volume of water under the earth's surface, as well as that upon it, gravitating to places where it can issue from the ground with the least resistance possible. Wells sunk near a river or near the sea coast will, if not drawn from too heavily, furnish fresh water which is flowing from inland towards the river or sea—the surface of the water in the earth being invariably, under normal conditions, higher than that in an adjacent river (*Fig.* 1, *Plate* I.). Of course, in an estuary or in the sea the rise of tide may cause the flow to be intermittent, and may even reverse it periodically; so that at high-water, the sea-surface being above that of the surface of saturation in the land, a certain quantity of sea water would penetrate the soil, rendering well water in the vicinity brackish, but flowing out again at low water, at which time possibly water intercepted by a well near the shore would be quite fresh.

In general, the depth below the surface at which water is found depends upon the nature of the rock, the contour of the country, and the amount of rainfall. It is easy enough, by boring or sinking a trial shaft, to ascertain the water level in the subsoil at any particular place. A more important question is, however, "How much water may a well or a bore hole in that situation be relied upon to yield?"

The yield of a well is governed by natural laws that are perfectly well understood, viz., the permeability or resistance of the subsoil to the passage of water through it, and the "head" afforded by the level of the surface of the subsoil water in the neighbourhood above the bottom of the well. It is necessary to admit, however, that difficulties of observation, and ignorance of facts, leave the data whereon alone a reasonably complete system of subterranean hydraulics could be founded far beyond our ken. In a hard impervious rock it may readily occur that, although by trial indication is afforded of water comparatively near the surface, it may be impracticable to obtain an adequate supply of water at a reasonable depth, on account of the very steep waterslope or head needed to force the required quantity through the surrounding rock to the well or bore hole in question (*Fig.* 2, *Plate* I.). A prolonged trial only can settle the question of yield definitely; but it is important to notice that, in such hard or slightly permeable rock, the draught from a well affects a comparatively limited area around it; and the supply of water may therefore be augmented by increasing the number of wells in the neighbourhood, whereas comparatively little such gain can be expected from the adoption of a similar course in a district where the soil is more permeable, if a single well gives disappointing results, when sunk to the limiting practicable depth. As regards quality, it is generally accepted that well water, when taken from a sufficient depth and under conditions that exclude surface impurities, is pure—that is to say, it is free from organic impurities. Its dissolved mineral contents, however, are frequently considerable, depending upon the character of the strata from which it is derived; and this deserves consideration in forming a judgment as to the suitability of these sources of supply, not only in regard to the constitutional effect of the consumption of large quantities of lime, magnesia and iron, which are the commonest minerals, but also in regard to the economical questions of the use of the water for washing and for industrial purposes. There is another consideration that should not be lost sight of, vague and indefinite as is present knowledge of the matter. Deep well water is free from organic impurity, because the rocks through which it has percolated have strained out from it the impurities with which it became associated ere it left the earth's surface, and, under the action of gravity, sought a subterranean course towards the ocean. Among the matters from which it is thus freed are the vast quantities of micro-organisms that inhabit surface waters of all kinds. These, we are told, may be harmless, but may be of a pathogenic nature; and it may therefore appear a common-sense view to take to regard deep well water, which is practically free from living organism of every sort—"sterile," as the biologists term it—as on that account specially suitable for dietetic use. It has, however, been demonstrated that organisms productive of or typical of disease exhibit more prolonged vitality in such sterile water than in surface water of reasonable purity, though containing large numbers of bacteria of what are believed to be a harmless kind. As if the latter, where they are already domiciled, combine to destroy the intruders, which, on the other hand, thrive better in the absence of such opposition. This accords with the practical rule approved by experience, that well water should be conveyed to consumers expeditiously, and should not be exposed to light and air in reservoirs before its distribution.

I dwell upon these preliminary considerations because the responsibilities of the engineer who undertakes a work of water supply are affected and influenced at every stage of the operations by the choice originally made of the source of supply, and knowledge of the character of various kinds of water and their several effects is an essential preliminary to the successful execution of such works.

It is needless to dilate upon the obvious necessity of excluding from the source, when selected, every cause of pollution, as far as is practicable. This is effected in the case of wells by lining them with brickwork and tubing for a considerable depth below the surface; in the case of streams and gathering-grounds by preventing the direct discharge of sewage into them and by reducing to its lowest limits cultivated land.

A review of the various systems in use for well sinking and boring would alone afford material for a lecture. The perfection to which boring-plant has been brought has had the effect of causing the old-fashioned sunk wells to be largely superseded by bore holes, the yield of which is quite equal to that of wells of the same depth. In regard to driving these bore holes, I must restrict myself to offering an opinion that for ordinary cases there is nothing better than the simple percussive method. A heavy chisel, or a crown containing several chisels, is suspended in the bore hole by rope or by rods from gear by which it is alternately raised and allowed to fall freely upon the bottom of the hole, a slow motion of rotation being imparted to the cutting tool during the operation. The *débris* formed at the bottom of the hole is raised by a small grab or cylindrical bucket pump let down from time to time. By this method bore holes are sunk with facility and without great cost to depths exceeding 1,000 feet. In lining the upper portions of wells and bore holes which pass through that portion of the strata which cannot be relied upon to furnish satisfactory water, care must be exercised to make a tight joint between the bottom of the lined portion and the adjacent soil or rock. *Fig.* 3, *Plate* I., shows bore holes sunk from a lined pump-well, the concrete floor of which forms a stop to prevent the access of surface-water to the bore holes.

The "tube well," which is a very suitable apparatus for obtaining water quickly from a considerable depth in loose strata, is formed of strong wrought-iron pipes of small diameter armed at the end with a perforated shoe; the tube is driven like a pile, additional lengths of pipe being screwed on as it descends. The sinking may often be facilitated by forcing water down the tube, thus loosening the soil about the shoe and lubricating the exterior of the whole length of pipes.

The friction of the soil is the principal difficulty in regard to lining bore holes of all sizes. This frequently determines the diameter, and thereby the depth to which they can be sunk. As the lining becomes earth-bound, the diameter of the bore hole has to be successively reduced, so as to admit of a fresh set of lining tubes being passed down inside the set last driven. Of course, where the general water level of a district is naturally situated at, or by pumping has been reduced to, a considerable depth below the surface, the pumps must be placed low down. And the practice is to sink wells to contain the pumps and rods, driving bore holes lower to collect the water. I hope my remarks will not appear too disjointed if, omitting all reference to pumps and mechanism for raising and forcing water, which could not be usefully reviewed in a few minutes, I pass to the consideration of the other great source of water supply, viz., the earth's surface.

Here we approach a subject that has, compared with that of subterranean sources, been reduced by observation and experiment to an exact science. The rainfall over any given area of country can be established by gauges, and the relation between that fall and the portion of it which flows away towards the ocean in streams and rivers on the surface may be readily ascertained. As a matter of exact measurement for the engineer's use, it is with the latter quantity we are directly concerned. Rain gauging is of extreme value in preliminary enquiries; but however accurately performed, it does not indicate what amount of water can be secured for use in any given district. It enables inferences to be formed as to the yield under similar conditions of similar districts, whose respective rainfall is known, and as to the probable yield of surface water at different periods of the year—this being, of course, largely dependent upon the variation of rainfall.

To this I would direct particular attention. Even in this age of analyses, I venture to think that the first business of the engineer is to look for a source that will provide an ample *quantity* of water.

The diagram (*Fig.* 4, *Plate* I.) indicates the average monthly variation of the rainfall in the south-east of Scotland during the year. The variation of rainfall throughout the year is very marked, and the quantity of surface water that can be collected for use in that district may be relied upon to follow the same rule of variation; though I beg leave to reiterate that the actual amount of water available can only be satisfactorily arrived at by direct gauging of the flow of the streams during a period as long as practicable, thus establishing a relation between the rainfall in its entirety and that portion of it which escapes evaporation, absorption by plants, and subterranean flow—the three elements of loss of water from catchment areas. If the source of supply is a river, obviously or by direct measurement exceeding the requirements at all times, it is only further necessary to be sure that the water is unexceptionable in quality, particularly in regard to its use for dietetic purposes. If, on the other hand, as is more frequently the case in civilized countries, the conditions of supply are such that, either from considerations of cost, as small an area of land as possible is to be reserved to afford the source, or, owing to other vested interests, the catchment area is laid under contribution to afford a prescribed flow of compensation water, works of storage become necessary to equalize as far as practicable the actual yield, variable, as indicated, and the supply, constant or variable, as the case may be. How variable such supply usually is may be realized by considering the exigencies of cultivation where irrigation is in question, and the more lavish use of water by communities in summer as compared with winter, in these latitudes. The consumption of water in towns may be, during the summer months, one-third more than the average, and this important element must not be overlooked in designing works for storage.

Suppose these factors known, and that the continuous line in the diagram (*Fig.* 5, *Plate* I.) is plotted to show the available quantities of water that may be expected from a given source during a period of three years. Plot upon the same diagram the estimated consumption (chain-dotted line) during the same period, the ordinates representing total quantities of "yield" and "supply" respectively at each point of the axis of abscissæ along which the time is measured.

The inclinations of these two curves to the horizontal denote the respective rates of the increase of the two quantities under consideration. Where the "yield" curve is more highly inclined than the "supply" curve, the water afforded by the source exceeds the demand upon it, and *vice versa;* where the two curves run parallel to one another the yield and supply are exactly equal. Hence, if lines parallel to the "supply" curve be drawn through the summits of the "yield" curve, the difference between an ordinate to such parallel line and that to the "yield" curve denotes at any point the quantity of water required to equalize the yield and supply up to that point. The *maximum* difference, which may be seen by inspection, measures exactly the amount of storage required to equalize the yield of the source and the draught upon it during the whole of the period under consideration. This graphic method is one of several that may be used for the purpose, but it is simpler than any other I know.

The period of three years selected for the diagram touches a practical point of great interest. The resources of meteorology have shown that if no definite cycle of rainfall can be ascertained or predicted, at least this rule may be accepted with great confidence, viz., three consecutive years of small rainfall occur at uncertain intervals, and the average annual rainfall of those three years is one-fifth less than the general average or "mean annual" rainfall, as it is termed. Practical considerations have led to the limiting size of storage reservoirs being taken, in general, as that requisite to equalize the yield of the catchment area and the supply during this period of three dry years. It may be desirable to depart from this rule, and, under other meteorological conditions, the data for the calculation of storage capacity may be altered; but the principle of which I have tried to indicate an outline holds good, that, given the particulars, which are generally determinate, the storage is a matter susceptible to exact calculation of a simple order; and without such investigation at the outset, rough-and-ready rules or empirical formulæ for arriving at the required estimate are employed at the risk of wasteful expenditure or inefficient results.

The formation of storage or impounding reservoirs is a subject full of interest, both to those who construct them, and to those whose lot it is to live under the shadow of the great walls or embankments that retain such stores of energy, potential for good or evil. The choice of the site for such a reservoir, the avoidance of faults, fissures, and permeable strata, the positions of the dam, the outlet and the overflow, the character of the retaining wall and the materials of which it should be constructed, afford scope for the exercise of the highest knowledge, experience and skill.

I cannot suggest that it is possible now to present even a general idea of the considerations, necessarily very variable, which enter into the proper solution of so complex a problem. Watertightness is essential, and that not only in the main body of the work, but especially in and under the foundations. The smallest fissure that permits the creep of moisture along it may, when exposed to a full head of water in the completed reservoir, become a spring, and develop into a stream sufficient to threaten the safety of the entire structure. Many reservoir dams are built upon fissured rock. In such cases provision is made for relieving the base of the structure from the pressure incident to the connection of the water in such fissures with that in the reservoir. The most frequent cause of the failure of reservoir embankments has been, not absolute weakness of the structure, but some bad joint in the work, or some fissure originated or developed by settlement. The results of settlement are among the most difficult incidents to provide against in the construction of the massive and lofty works employed for the formation of impounding reservoirs. So far has this been recognized that it may be regarded as an established rule that the outlet works of such reservoirs—both as regards the ordinary overflow and the draw-off pipes and valves—should be constructed in and through the original solid ground adjacent to the embankment. The outlet pipes are, in the best practice, carried either through a tunnel pierced round one end of the embankment, or in a culvert formed in the solid ground beneath it; and a further leading principle is that the valves commanding outlet pipes shall be placed near their inner end, so that in case of fracture of the pipe, the water may be shut off from the interior of the work. This is specially important in earthen embankments, which are naturally so susceptible to damage by scour. An embankment of earth of the ordinary type in this country depends for its stability upon its impermeability. This is secured by the vertical wall of puddled clay running longitudinally through the middle of it, and carried down through the original ground so as to join the impermeable strata in the bed of the valley—it may be at a considerable depth below the surface. The search for such impermeable strata, when their position has not been previously accurately ascertained by trial pits, has sometimes led to vast trouble and expenditure in sinking the puddle trench to depths exceeding 150 feet.

It is not an uncommon practice now to substitute concrete for puddle in these deep curtain walls. The real function of the earth in an ordinary embankment is to support and protect the puddle wall, which actually retains the water in the reservoir. Hence the dimensions of such embankments are not determined by reference to the forces of water and wind pressure which they are called upon to resist, and for which they always possess a vast margin of strength, but in relation to the natural slope or angle of repose for the material in question. This ordinarily leads to a slope of about 1 in 2 on the outer side, and 1 in 3 or 1 in $3\frac{1}{2}$ on the inner side, where the saturated soil naturally tends to assume a flatter slope. In high embankments it may be advisable to widen the base further, with a view to reduce the pressure on the foundation. Equally with the outlet arrangements, the provision for overflow demands scrupulous attention and care in design and in execution. In design, because its capabilities depend upon conditions that are by no means easy to settle without trial; in execution, because in high flood these works are submitted to the severest test imposed upon engineering structures—and during such times there is no opportunity of rectifying any error or fault of construction. The overflow, or "waste weir," must be capable of discharging the greatest flood of the district without risk of so accumulating the water as to top the embankment, which would lead to immediate and complete disaster, and also without involving a discharge of such depth and velocity as to threaten the structure of the weir and channel. It is needless to dwell upon the solidity and perfection of the workmanship required in structures exposed to forces such as those under consideration. Massive and well-jointed masonry and concrete of the best quality are the materials upon which experience has shown that reliance may be placed. The slope of the waste channel should be as slight as practicable, and if the entire work can be executed in the natural ground away from the embankment, so much the better.

The main features of the two leading types of earthen embankment are defined by the outlets. In one case the outlet culvert is constructed in the solid ground quite underneath the embankment, and in a situation where it is free from the influence of the spreading action exercised by the mass of earth in settling. In the other case the outlet is carried through a tunnel in the rock adjacent to one shoulder of the embankment, a practice which is now-a-days approved as the most satisfactory in all respects.

The precautions taken against settlement should be noticed. In the old embankments which the outlet culvert traversed, one of the features was the "slip joint" in the line of the puddle wall. This was a section of the culvert formed with vertical dry joints in line with each side of the puddle trench, by which means the natural (and prolonged) settlement of the puddle wall was accommodated by the descent of the collar portion of the culvert, thus avoiding bending and possible fracture of the latter.

The practice of substituting concrete for puddle in the lower part of the wall, already referred to, has the advantage of avoiding this trouble. But where a massive valve tower joins the simpler and lighter construction of the culvert a slip joint is necessarily introduced.

I must pass from the subject of dams of earth by saying that, troublesome as is the question of settlement in regard to these, it is vastly greater with dams of concrete and masonry—such as are now becoming more common in every part of the world. With earthen embankments, the difficulties arising from settlement are restricted mainly to those places where want of homogeneity is caused by the introduction of unyielding iron and stone into the mass of plastic earth. By avoiding the incorporation of rigidly-built work with earthwork, the latter may be relied upon as absolutely as the natural solid ground; but it is far otherwise with walls of masonry, set in cement that is often adapted to ensure speedy rigidity, whilst the increasing superincumbent mass promotes settlement and consolidation of the portion below it. A further difficulty encountered by the engineer who chooses to construct a dam of masonry arises from the effect of changes of temperature upon the somewhat rigid mass of the work; whilst the length and the exposure of these structures to atmospheric influences ensure pretty free play for the co-efficient of expansion—which is not inconsiderable. This suggests some superiority for the arched type of dam, which may accommodate itself, by variation of curvature, to elongation or contraction due to change of temperature. In regard to the prevention of fracture by settlement during or after construction, I can only dwell upon the necessity for avoiding abrupt changes of level in the work, and for paying consideration to the form of section at various depths, with a view to equalize to some extent the settlement in different horizontal planes. Most important of all, it may be noticed that there is observable a tendency on the part of engineers to employ slower setting limes and cements, which may permit a natural yielding and settlement of the mass before it assumes a rigid condition. It is a matter of some wonder that, with the numerous analogies in physical science of the fragile nature of bodies when they become rigid in substance under conditions of internal stress, the state of great masonry dams, cemented together with Portland cement of a high tensile resistance attained in a comparatively short time, has not invited attention earlier.

The subject of masonry dams is at once so attractive and so complex, that I beg leave to urge those who have the opportunity to use it in carefully investigating the theory of these structures. For hundreds of years they were built as massive, wasteful walls by ignorant copyists of the earthen mounds which they succeeded. Hardly more than a quarter of a century ago, Delocre, Graëff and Bouvier, with the inspiration of French science in such matters, examined the question of the stability of such walls, on the assumption of rigidity and homogeneity, from first principles. The result was the fine profiles of the well-known Furens dam, the dam of Ban, and others. It was due to Major Tulloch, at that time occupied with the question of the Bombay water supply, that the question of this new principle of construction, as it was called, was submitted to Rankine, who at once pronounced in its favour, and indicated an empirical rule for finding an approximation to the theoretical profile under certain restricted conditions. Great masonry dams have since been built in India and in England, and this type promises to supersede largely embankments of earth in many situations, as safer, more economical, and capable of being carried to vastly greater heights than the latter. The "Vyrnwy" dam (*Fig.* 1, *Plate* II.) and the "Thirlmere" dam (*Fig.* 2, *Plate* II.) show a conservative design, slowly departing from the earlier massive earthwork structures. The "Periyar" dam (*Fig.* 3, *Plate* II.) suggests that Indian engineering art is somewhat freer from the trammels of former English practice, and the result is a strong argument in favour of the scientific profile. The Chartrain dam (*Fig.* 4, *Plate* II.), recently built in the south of France, exhibits the high-water mark of French engineering skill in these works.

The important features in design are to so arrange the form of the section that there shall be no tension at any point, that the maximum compressive stress shall not exceed a prescribed safe amount, and that the structure shall be impervious to water. The mathematical considerations involved in a general statement of this problem are so complex as to become unmanageable. That is why Rankine chose a reasonable approximation in his logarithmic profiles, in preference to troubling further with expressions which he found it impracticable to integrate. Recently, however, processes have been developed for the solution of the problem which, without any high flights of mathematics, lead to a definite and satisfactory result, as a matter of pure statics dependent only upon the data and conditions laid down at the outset of the investigation. I do not venture to involve you in the labyrinth of mathematical argument that any such process, however simple, must involve. You may be of opinion that, having regard to our ignorance of the strength, elasticity, cohesion and distribution of stress in the most homogeneous walls, such investigation must be based upon data too uncertain to lead to any satisfactory conclusion; but I venture to propound the view that a precise knowledge of any such question in its theoretical aspects (whatever their value as an absolute guide) is indeed a most valuable preliminary step to the formation of a sound judgment upon the general question, taking into account all those elements with which experience may reckon if it is unable to assign exact values to them. I have so far alluded to stone or concrete dams which rely upon their mass and weight. There is, however, another type worthy of notice, which depends upon the principle of the arch for its stability. The instances are few. The Zola dam (*Fig.* 5, *Plate* II.), in the south of France, the Sweetwater and the Bear Valley dams (*Figs.* 6 and 7, *Plate* II.), in California, are the principal examples. The radius of the Bear Valley dam is 335 feet, and the stress in the masonry cannot be less than 40 tons per square foot when the reservoir is full. This is a structure to command wonder rather than imitation, and it is satisfactory to know that, having served well its purpose and the irrigation company who built it, a stouter and less elegant structure is projected somewhat lower down the valley that it spans.

With the collection and the storage of water, its conveyance to the place of its utilization must rank as the third main feature of water supply. And the vital question of measurement of water is so closely connected with the latter point that it may well be glanced at here. The kind of measurement with which we are generally concerned in regard to water supply is one rather of rate than amount. The question to be answered is, "How much water can be obtained or delivered per hour, per day or per week, to fulfil certain requirements?" The cross section of a stream of water, and its average velocity in passing that section, determine fully and precisely all that is wanted, and water gauging in its various complexities is devoted to ascertain those two data. Whether it be a measurement by notch gauge, or by orifice, or by current meter, in a conduit or in a pipe, these are the elements sought. The theory is to regard the water as a fluid free from internal friction, and susceptible only to the action of gravity and to the influence of friction from the surface it flows over, in a degree dependent upon the area of the surface in question and the square of the mean velocity of the stream. Its velocity, treated as that of a falling body, is expressed by the common relation $v^2 = 2gh$, which is the basis of all the formulæ for gauging, and for flow in streams and pipes; rectification being introduced by means of constants derived from experimental results as required.

To consider the application of the law to flow in a stream, or in a pipe, of given cross-sectional area A, length l, and inclination i; if the wetted perimeter of the conduit is p, and the velocity of flow is v, it appears from the foregoing relation that $v^2 \times p \times l \propto A \times l \times i$—equating the resistance to the gravitational force acting on the water in the direction of the surface of the stream.

Hence $v = c\sqrt{\frac{A}{p}i}$, where c is a constant.

$\frac{A}{p}$ is generally written m, and the expression thus becomes $v = \sqrt{mi}$, the well-known Chezy formula proposed in 1775.

The quantity m, the $\frac{\text{cross-sectional area of the stream}}{\text{wetted perimeter of the section}}$, termed the *hydraulic radius*, or *hydraulic mean depth*, is of fundamental importance in reference to the design of channels and conduits, which are constructed so as to give as large a value as practicable to this element, thus ensuring the required flow with the least possible loss of "head," which is generally a consideration of importance. Flow in an open channel is too simple a matter to dwell upon, but in a closed main the conditions are not quite so obvious. The delivery of a water main under pressure depends, like that of all other streams, upon its sectional area and velocity of flow. The velocity at every point is due to the fall of pressure or head from the commencement to that point, less the head consumed in overcoming friction. This latter amount varying with the length of pipe, the loss of head required to ensure the uniform flow sought in all water mains varies directly with that same length, and, taking the water level at the inlet of the pipe, and the head or pressure at the outlet end, a line joining those two points gives the "hydraulic gradient" or pressure curve for every point of the main under consideration. This hydraulic gradient is the first conception in every scheme of aqueduct design. To ensure uniform flow, every point of the aqueduct or pipe should be below this line (*Fig.* 2, *Plate* III.). Of course, important as the "hydraulic gradient" is, it is only a convenient conception, and is probably seldom precisely realized, in fact, according to the intentions of the designer of an aqueduct. It is sometimes alluded to as a vital matter that a line of pipes should not touch or exceed, however slightly, the hydraulic gradient line at any point. Undoubtedly this is desirable, but nothing extraordinary will happen if, in a long pipe line, the hydraulic gradient is topped by the main, provided that the latter rises but slightly above the gradient in comparison with the length of the pipe. The delivery cannot be affected, if at all, beyond what is involved by the square root of the altered slope. The true "hydraulic gradient" is by no means a simple straight line: loss of pressure, due to the head consumed in giving the initial velocity to the water in overcoming resistance at bends, screens and valves, would all have to be taken into account in plotting the true gradient, which is indeterminate with any high degree of accuracy. The important point in laying a water main is to provide against contraction of the area by accumulations of air at summits of the pipe, and deposits of dirt in the depressions. The provision against these effects, made by air valves in the former situations and by scour valves in the latter, involves continual attention and care. There are, indeed, self-acting air valves, but in waterworks practice automatic apparatus of this kind is to be viewed with some suspicion, tending, as it does, to create a feeling of reliance upon mechanism, which may fail at a critical juncture unless kept very regularly in perfect working order. The other principal accessories of a water main are the stop valves, placed at suitable intervals to enable sections of the pipe to be isolated and emptied rapidly for repair (*Fig.* 1, *Plate* III.), and self-closing valves, which are designed to close automatically in case of a bad burst, thus preventing waste of water and damage arising from it. All such apparatus must be worked frequently if it is to be serviceable when called upon. That is a leading rule applicable to all moving parts of mechanism employed in works of water supply.

There is one feature in regard to the delivery of a water main throttled by an accumulation of air at one of the summits to which I direct attention, as it illustrates the whole subject in a very general way. Suppose the air valve at the summit ceases to act, this portion of the pipe will gradually become filled with air, the pneumatic pressure obtaining there determining the level of the water in the lower portion of the pipe, and also the overflow at the summit, which would be, under these circumstances, the delivery of the whole main. This illustrates an extreme condition of affairs (*Fig.* 2, *Plate* III.). Long before this came about serious diminution of the flow would have become apparent. The remedy is to keep the summit free of air by a suitable air valve.

The subject of pipe aqueducts naturally invites attention to the construction of these works. Formerly the pipes, when used, were of wood, with spigots and faucets roughly forced together; cast iron pipes followed, and are yet the most largely used of all types, although in new countries, where carriage is expensive, thin wrought-iron and steel pipes are superseding those of cast iron. Assuming pipes to be soundly manufactured, the method of jointing presents a highly important matter for attention in laying a main. The spigot and socket system is generally adopted for cast-iron pipes, and frequently too for wrought-iron and steel pipes, although, in the case of the latter, the collar or double-socket joint possesses many advantages. The joints are formed either by the spigot, accurately turned, being forced tightly into the socket correspondingly bored out, or by caulking the joint with lead. The former system possesses many advantages—it is cheap, rapid, involves less skilled labour, and avoids the difficulties inseparable from cutting joint holes in the pipe trench for caulkers to work upon lead joints. On the other hand, the main is inflexible, and trouble sometimes arises from expansion and contraction due to change of temperature. Lead joints permit considerable changes of direction to be made in laying the main, without the introduction of special bends, and in undulating ground this may reduce expense; if found to leak, a few strokes of the caulking hammer may put the matter to rights, and every joint is itself an expansion joint. It is a desirable practice to introduce, on this account, lead joints at frequent intervals in a line of turned and bored pipes, and it is customary to form the sockets of such pipes so as to admit of their being run with lead and caulked outside the bored portion, in case of bad fitting in the latter. The union of adjacent portions of a main, and the insertion of valves and other special pipes, is best effected by collars with lead joints, which can be melted or cut out if it is desired to withdraw the specials for renewal or repair. Uniformity of temperature is difficult to work to in laying a pipe aqueduct, but it is highly desirable to approach to it as nearly as possible; especially in large mains, in which great alternations of heat and cold may start the joint and do mischief that does not become apparent until after the work has been covered in and the main subjected to pressure. The care necessary in handling cast-iron pipes is not, perhaps, generally appreciated. There is a tendency to fancy that, being of iron, they will stand knocking about. In truth they are, having regard to their weight, fragile, and, even with the utmost attention, fine cracks, possibly merely superficial, cannot be always avoided. Such cracks, when subsequently exposed to the internal and external pressures to which the main is subject when laid, and to the violent forces applied by heat, driving, and caulking during the operation of making the joints, develop and tear through the metal, with, of course, the necessary result of loss of water. Security from such faults can only be attained by extremely careful inspection at every stage, both of manufacture and of construction of the main; cracked pipes being rigidly excluded, however slight the fracture, and the damaged portions cut off. I dwell advisedly upon the importance of attention to the construction of pipe aqueducts. It has been too much the custom to assume that, or act as if, pipe-layers' work was hardly worthy of an engineer's notice. In truth, when the long lines of conduit, buried underground in any ordinary system of water supply, are considered, the facility with which leaks may escape detection, the number of fractures which close inspection will reveal in almost any pipe, it may reasonably be asserted that, on economical grounds, no pains should be spared to ensure perfection of workmanship in a pipe aqueduct, especially one liable to high pressure. Nor are modern aqueducts, although generally buried, uniformly devoid of the attractive features of engineering art. Some of the valley crossings of the new Birmingham aqueduct are worthy to rank with any of the classic Roman colonnades, having regard to the skill and boldness they display. A feature of pipe aqueducts which must not be overlooked is the provision of relief tanks, with overflows, by which the head in a long main may be broken at intervals, so as to avoid the risks arising from accumulated pressure in the case of partial or complete stoppage of the flow.

The kind of provision made to equalize, daily or hourly, differences between supply and demand also deserves notice, applying both to gravitation mains and pumping supplies. In *Fig.* 3, *Plate* III., is shown a water tower recently built in Lancashire. It is an interesting type, as it carries two tanks at different levels, serving two zones of supply; both more economically, as not necessitating the low-pressure supply being raised to the elevation required for the service of the higher zone; and more efficiently, as not exposing the service pipes of the lower zone to an unnecessarily high pressure of water.

I do not propose to touch the subject of purifying water, which is an art in itself, beyond alluding to the simple practices of straining and filtration, as generally carried out in the case of even the most unexceptionable surface waters. Straining through copper-wire gauze of fine mesh has become a recognized practice before admitting water into an aqueduct. And there is little doubt that, in addition to its desirability from the point of view of the consumers, it is most useful in preventing fouling of the main, thereby prolonging its life. The straining well at the outlet from Thirlmere is shown in section in *Fig.* 4, *Plate* III.

As regards filtration, the passage of water through a bed of clean sand 2 or 3 feet in thickness, at a moderate rate of 4 inches to 6 inches per hour, is a process so efficacious in freeing the supply from organic matter of all kinds, that no system of supply of surface water can be deemed complete without it. The process is, as previously implied, unnecessary in the case of well water which has been thoroughly filtered before being pumped. The sections of one of the newest London filters (*Fig.* 5, *Plate* III.) indicate the most recent practice in this respect. The chief feature in working is steadiness of operation, to secure which the design should provide for uniform flow through every portion of the filter so far as it may be capable of practical attainment.

Time obliges me at this point to bring my observations on the subject to a close—not with unmixed satisfaction, but with a hope that, little as it may have been possible to impart of immediate practical utility, I may have been fortunate in suggesting some of the lines upon which the matter of water supply is to be successfully prosecuted. In conclusion, I wish to express my thanks to Mr. G. H. Hill for the assistance he has rendered in permitting me to exhibit illustrations of the Thirlmere works, and my acknowledgments to the *Minutes of Proceedings of the Institution of Civil Engineers* for the views of the series of dams.

PAPER VIII.

THE MECHANICS OF HORSE HAULAGE.

BY T. H. BRIGG, ESQ.

Paper read before the Society of Engineers, and reproduced by kind permission.

[THIS paper has already appeared in the *Journal*, and is repeated, by request, in the *Professional Papers*.]

IT may appear improbable, and indeed, almost incredible, that there should remain to this day anything of radical importance to be said on the mechanics of horse haulage. It is the object, however, of the author to show that, notwithstanding the writings and inventions from the earliest times to the present, the economical application of the power of a horse, and the true nature of the mechanics of that power, have never yet been completely comprehended or ascertained. The writings of Edgeworth, Ackerman and others of nearly a century ago did some good by directing attention to parts of the subject, but even these and other able writers, who have followed them down to recent times, have treated the subjects of draught and haulage mainly with reference to angle of traces and road resistance. The one has followed the other with but slight advance, and they have wanted that change in the direction of thought which would have enabled them to have included the horse, the vehicle, and the connections between them as the mechanical combination with which they had to deal in their endeavour to minimize the expenditure of energy by the horse in the performance of a given amount of work.

An explanation of the nature and direction of the forces which come into play in hauling a vehicle may be best commenced by reference to a simple illustration, afforded by the every-day practice of the London costermonger.

The author, stopping one of these men one day, asked him why he walked at the rear of his cart in the manner shown at *Fig.* 1 in preference to that in *Fig.* 2.

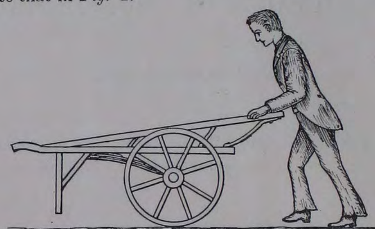


Fig. 1.

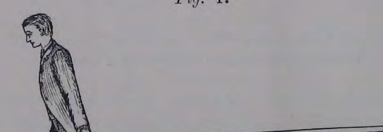


Fig. 2.

His prompt reply was, "Oh, it's a lot easier at the back than having hold of the handles in front." If he were in front, he said, he had to pull all the way, but if he were at the back, all he had to do was to lean on the back-rail and the cart would go by itself. The reason for this remark is obvious, although it is not strictly true. The cart went no easier, but he applied his force in such a way that little was required to effect the movement, and it was easier to himself The following diagrams will aid in realizing the real facts, and why it is that the man found it so much easier one way than the other.

Let *Fig.* 3 represent a man pressing 12 lbs. downwards at P upon a see-saw to balance a weight of 10 lbs. at W. If the man's own weight be 150 lbs., then (150 − 12 = 138 lbs.) deduct 12 lbs. from 150, it is found that the man will now only bear 138 lbs. on his feet when standing, because 12 lbs. of his weight, together with the 10 lbs. at W, is now all resting upon the fulcrum F, or a consequent pressure of 12 + 10 = 22 lbs. upon that point.

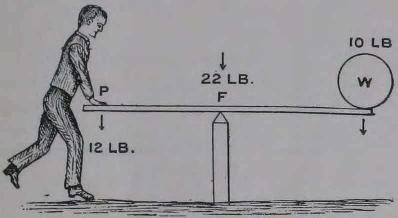


Fig. 3.

Now from *Fig* 4 can be seen what difference will be caused by the load W being placed equi-distant between P and F. It will be found that the man must now support 5 lbs. of the weight W, and that the fulcrum F must support 5 lbs. of the weight W, therefore the total weight upon the man's feet must be 150 + 5 = 155 lbs, as against 138 lbs., or a difference of 17 lbs. more than in *Fig.* 3.

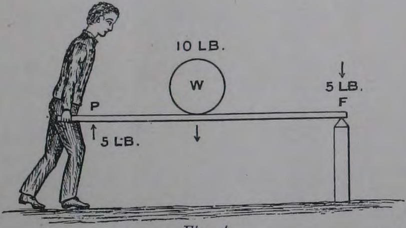


Fig. 4.

If it now be imagined that the fulcra in each of the preceding figures are placed on wheels, as in *Figs.* 5 and 6, and that the men are in the act of walking at the rate of four miles an hour, and since it is known that every 1 lb. of the man's own weight, or added weight, equals 2 lbs. percussion at his feet at every stride, then it is found that the man in *Fig.* 6, by having 17 lbs. more weight on his feet than in *Fig.* 5, must consequently suffer 34 lbs. more percussion upon the muscles and tendons of his feet and legs than in *Fig.* 5. But since the man in *Fig.* 5 presses obliquely downwards in order

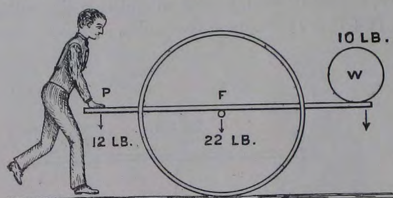


Fig. 5.

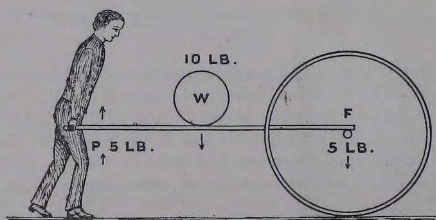


Fig. 6.

to balance W, then, by effecting the 12 lbs. downward thrust, the wheel must sustain this 12 lbs., together with the load W; therefore the wheels of the cart must be carrying a greater load than in *Fig.* 6, and, therefore, must require a greater horizontal thrust to overcome the greater resistance which must result from the greater load. But this illustration will aid in seeing and realizing what it really was that caused the coster to make the remark he did. The real, and not the imaginary, cause can now be seen; the man having been unconsciously relieved of 12 lbs. of his weight in the act of thrusting in the one case, and in the other had his weight increased by 5 lbs. when in the act of pulling; then there is a difference shown as before stated, of 17 lbs., or a less percussion of about 34 lbs. at every stride. There can be no wonder, therefore, at the man thinking that the cart went by itself; it actually required more horizontal force because of the added weight, but the man's relief was so much in excess of this that, in comparison, the cart seemed to go by itself.

Now horses may be made to believe the same by giving them similar conditions to those the coster made use of, whenever we can do so to their advantage. But before going further it may be asserted as a known fact that a man or a horse can travel easier and further on good roads with a vehicle than he can travel without. For instance, it is known that a man can travel further and easier with a bicycle than he can without, unless the road is so bad that he cannot afford either to ride upon it bodily or to recline upon it when walking by its side. The same applies to a nurse-maid with a perambulator. She can walk further with it than she can without it, although she takes the child with her. In the same manner, and governed by the same laws, horses can be enabled to travel further and easier with their vehicles and loads than they can travel without them, provided they be allowed to carry a part of their own weight upon the wheels whenever the condition of the road will permit, and this will be found possible over about seven or eight-tenths of an average journey on good Macadam roads. During the remaining three or two-tenths of the journey it may be found necessary that the horse should require added weight, or to carry a portion of the vehicle or of the load, as, for instance, when horses climb hills with loaded vehicles. This has been known for generations, even as far back as the time of the Charioteers, who used to stand forward when ascending and backward when descending hills, and in every quarter of the globe to-day it is found of great benefit to a horse in climbing if the load be moved forward, and *vice versâ* when descending hills, with two-wheeled vehicles. Owing, however, to people never having seen or been comprehensively taught the fundamental principles involved, they have not realized the exact reason for this, nor have they seen how much more im portant it is that horses should have the same two-fold mechanical advantage conferred upon them when drawing a four-wheeled vehicle, which is, as a rule, much heavier, and, by reason of its smaller wheels, more difficult to draw. They have not seen the practical application of the principles, nor of the above-mentioned acts of the Charioteers, or of the modern carter. The ignorance of people or the want of a knowledge of the economic principles involved, which is the same thing, has resulted in causing horses, particularly with four-wheeled vehicles, to work under conditions which have been a constant drain upon their energy, to their own discomfort and to their owners' loss.

Having made clear the importance of relieving the animal of some of his own weight, which is from 50 to 100 times greater burden to him than so much weight upon the wheels when travelling on a good road, it must next be shown how important it is that the horse should have added weight when in heavy draught. Horses and men are living self-weighted levers. The length and height of the body, and the direction of the force applied, will determine the length of the lever. Levers may be straight, or they may be bent in any desirable shape; they may be of wood, of iron, or of flesh and bone; therefore, the fact that a man or a horse is a living being does not alter the fact that he is a combination of levers, and that in his case, as in all others, the amount of force which he can exert depends upon the increased and decreased purchase of these, which is determined: (1), by the total length of the lever, and where the fulcrum is placed; (2), by the direction and magnitude of the power applied.

For instance, *Fig.* 7 is a lever 60 inches long and 60 lbs. in weight. If the fulcrum be put in the middle, and if the bar be uniform in weight from end to end, it would be balanced.

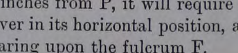


Fig. 7.

But if we remove the fulcrum to F, 15 inches from P, *Fig.* 8, then, since the total weight of the bar is 60 lbs., and since its centre of gravity is at C, 30 inches from P, it will require a force of 60 lbs. at P to balance the lever in its horizontal position, and, therefore, there will be 120 lbs. bearing upon the fulcrum F.

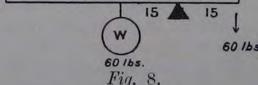


Fig. 8.

Now it can be seen how the forces which a self-weighted bar of iron can effect can be turned to profitable account. The bar shall in this case rely entirely upon its own weight. *Fig.* 9 is a repetition of *Fig.* 8, with a friction pulley R and a loaded wagon added. Again, since a lifting force of 60 lbs. is exerted at P, and a connecting cord is passed under the friction pulley R and attached to a wagon, it will be found that the effect of the 60 lbs. bar, with the fulcrum as shown, would actually exert sufficient force to keep a load of over

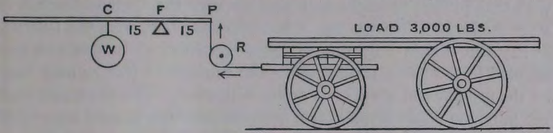


Fig. 9.

4,000 lbs. on wheels in motion on a level road. But inasmuch as the iron bar is inanimate, and incapable of effecting self-locomotion, it is unable to advance and keep ahead of the vehicle, as is the case with the animated levers constituted by man and beast, both having the power of self-locomotion.

But it may be said that a horse does not exert his power round a friction pulley; neither does he constitute a straight lever. It is true he does not, but he constitutes a bent lever,

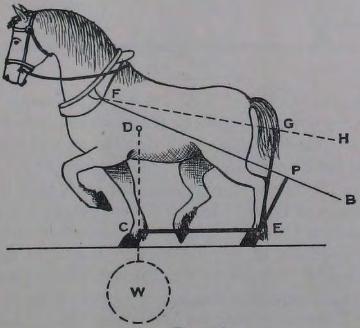


Fig. 10.

which produces exactly the same result. To determine what the levers are in a horse, let *Fig.* 10 represent one in draught; suppose the total thrusts to be effected by the off-side foot E through traces

F B, then E becomes fulcrum, from which draw line E P at right angles to F B. E P will thus form one arm of lever, and if D represents tho centre of gravity of the horse, then draw line of gravitation D W, when W will represent the total weight of the horse, whilst a horizontal line from E to D W cutting at C will give C E the second and long arm of the lever represented in the horse, with that particular angle of trace—to vary the angle of trace is to alter the lever—thus we get a bent lever C E P, with the fulcrum at E. But this is only one of the two, three, or four levers, constituted in the horse, according to the number of feet he may have on the ground and what he is doing with them. Therefore, although the purchase of the lever shown is about as three against two—that is, the length of E C equals three, whilst E P equals about two—yet, when all the levers in play are taken into consideration, there will be no such advantage.

For the present it will be better to revert to the leverage shown in *Figs.* 8 and 9, but with a bent lever instead of a straight one. In *Fig.* 11 we have a bent lever C F P. If 60 lbs. vertical pressure be

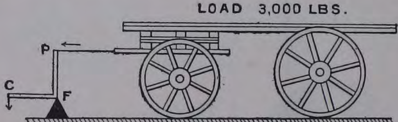


Fig. 11.

exerted at C, since C F and F P are equal in length, and F being the fulcrum, we now get precisely the same result as in *Fig* 9. If now the 60 lbs. (or 60 stones) is all that the man or horse can bring to bear upon the lever at C, and if it requires 70 lbs. through the trace to move the wagon on any particular road, then it is clear that an added weight of 12 or 14 lbs. at C would easily move the wagon. Without the added weight neither the horse nor the bar of iron could exert the limit of their strength. Hence, in the haulage of vehicles by horses, in order to give the animal the greatest possible control over his load, when the latter requires a heavy pull, it is of the highest importance that he should be able, automatically, to transfer the necessary weight from the load to his own body, thus doing two very important things, viz., reducing the load on the wheels and enabling himself to make use of his muscular strength, which he could not otherwise do. Therefore, to secure economy of horse power, or, in other words, to enable him to reserve or husband his forces, and to enable him to earn the most money at the least cost, it will be found that two conditions are absolutely essential.

(1). That he shall never be compelled to carry more of his own weight upon his feet than is absolutely necessary, because it is his own weight that shatters his legs and feet more than anything else.

(2). Since he must draw his load up hill, he must have those conditions automatically conferred upon him which will enable him to temporarily increase his own weight, and at the same time reduce the load on the wheels, thus giving him a two-fold mechanical advantage.

Apart from the distribution of the work among different sets of muscles, instead of exhausting the horse by the present method of throwing the work upon one set only, he should, if possible, be yoked in such a manner that the vehicle is to him what a hand-cart is to the coster—and the perambulator to the nurse-maid—a source of help over the greater portion of the journey. The laws which govern the power and endurance of man also govern the power and endurance of the horse.

For explanation of some further points in the mechanics of haulage, some simple cases may again be taken. Take, for instance (*Fig.* 12), a common wheelbarrow with a boy for a load. It is im

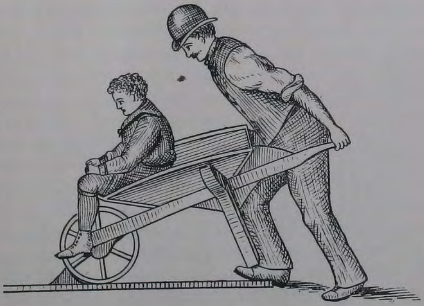


Fig. 12.

possible for the man with all his power to thrust the barrow over an obstacle, or over a curb-stone, yet the man very soon finds how easy it is if he will turn and pull the load, as in *Fig.* 13, or if he will place his knee under the barrow and effect a desirable lift.

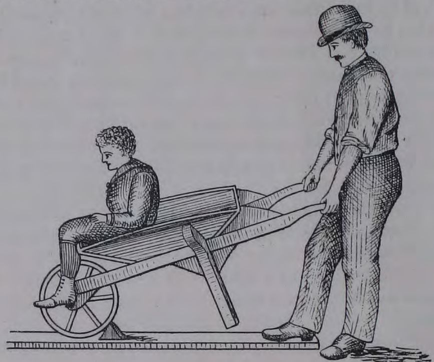


Fig. 13.

Thus it will be observed that conditions may be imposed upon the man which make it either possible or impossible to do the desired work, although the obstacles and gross load in each case remain the same. Again, it will be noticed that the nurse-maid wheeling a perambulator also prefers to thrust her vehicle, just as the man prefers to thrust his barrow. She turns round and pulls the carriage up on to the footway rather than attempt to thrust it, because she has found by experience how much easier it is. There are exceptions, of course, which can be explained. There is another important point in both these cases, and unless there were some tangible difference between pulling and thrusting the vehicles, or, in other words, if the work done in thrusting is equal to the work done in pulling, and *vice versâ*, then it would be difficult to understand why it is that both the man and the girl, having pulled their vehicles on to the footway, will immediately take the trouble of turning round again, preferring to push rather than pull their loads. The result of the author's investigations has led him not only to realize exactly why this is the common practice, but to see how absolutely imperative it is in order that the greatest amount of work should be done with the least expenditure of energy.

Before proceeding with further explanation of this by means of diagrams, it is necessary to point out that it is not always easier to push a cart than to pull it. This fact will be gathered from statements already made, and its connection with horse haulage must be explained. It is important at this stage to make clear what is to be understood by "pushing" and "pulling," because a man can walk in front of his cart and still push it, and if the load on the wheels is so placed that it tends to raise the shafts to such an extent that the resultant of the force necessary to hold the shafts down and the force from the centre of the wheel to the man's hands shall fall in advance of his feet, he will be distinctly pushing his cart, and not pulling it, although the load is following behind. It is highly important that this should be understood, but it cannot be done so thoroughly without a knowledge of mechanics, and particularly the parallelogram of forces. For instance, if a common wheelbarrow is taken, and the forces brought to bear upon the man and upon the simplest vehicle used are plotted out, perhaps it will convey an insight into the whole principle upon which ease of transportation can be secured.

The man in this case being the motor, and his motor force being vital, it must, obviously, be wise on his part to find out the easiest way of accomplishing his task. If there is one way easier than another, some men are sure to find it out. In fact, everyone likes to secure the greatest ease and comfort that may be possible under the circumstances. Let *Fig.* 14 represent a man pulling a given

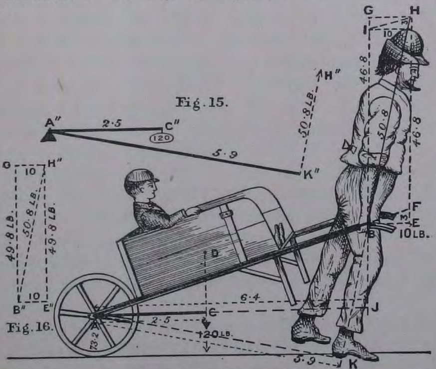


Fig. 14.—PULLING.

load as shown, the gross load being, say, 120 lbs.; assume the centre of gravity of vehicle and load to be at D, A the centre of wheel, and B the handles or point of application of the man's force. To indicate the levers brought into use drop a vertical line from the centre of gravity D, and from A draw a horizontal line cutting the vertical at C, A C 2·5 will represent the short arm of the lever constituted by the barrow, whilst A B represents the long arm. But, as the man's force is not applied at right angles to A B, but in the oblique direction of B H, then, to find the magnitude of that force which is keeping the load in motion, we must extend H B downwards and in the same direction until a line at right angles thereto will pass through the centre of the wheel, giving us the dotted line A K 5·9. Since A K equals 5·9, and the force applied is at right angles thereto, it is now easy to ascertain what that force is. If 120 lbs. be exerted at C 2·5, it will require 50·8 lbs. at B in the direction B H, because the purchase of A B is reduced to that of A K 5·9 by reason of the direction of force, so that as $5{\cdot}9 : 2{\cdot}5 :: 120 = 50{\cdot}8$. Therefore, if 50·8 equal parts be set off upon the line B H from B, cutting at H, and if the parallelogram B F H I be completed, then B I will represent 46·8 lbs., which would be necessary to support the barrow shafts vertically at B. [*Fig.* 15 represents the lever constituted by the barrow.]

In proof of this, if the same vertical line be continued downwards so that the horizontal line A J will intersect it, then A J will determine a purchase of 6·4 as against A C 2·5, so that as $6{\cdot}4 : 2{\cdot}5 :: 120 = 46{\cdot}8$ lbs. And since 50·8 lbs. through B H will both support and pull the barrow, then B E (10 lbs.) will represent the horizontal component. Thus it is proved that whilst the man is in this case supporting 46·8 lbs., he is at the same time effecting an obliquely upward force of over 10 lbs. from A to B through F, which we shall find to be effective in lifting 3 lbs. from the load and in adding E F (3 lbs.) to the man's weight upon his feet in addition to B I (46·8). Thus the parallelogram (*Fig.* 16) will represent the component and resultant forces exerted, as before shown. $B'' E''$ being the horizontal, we now find, by drawing $H'' G''$ parallel with $B'' E''$ that the vertical $B'' G''$ will now equal 49·8 lbs., being the total effective lift at B, whilst in the act of pulling.

Thus it may be assumed the man's natural weight is equal to 12 stone, or 168 lbs., then $168 + 49{\cdot}8 = 217{\cdot}8$ lbs. upon the man's feet, and only 70·2 lbs. on the wheel whilst the man is in the act of pulling the load. Now it may be seen what difference it makes to the man between pulling and thrusting. In *Fig.* 17 there is the same man

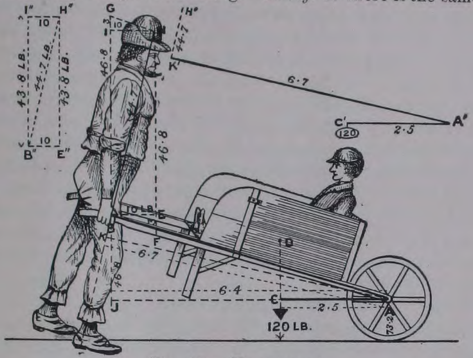


Fig. 17.—THRUSTING.

pushing the same barrow and load, consequently, as in *Fig.* 14 it will require a force of 46·8 lbs. at B to support the barrow shafts while at rest, it may be assumed that the load will require the same horizontal force of B E (10 lbs.) to produce motion. But since the pushing force must be exerted from B to A (the centre of the wheel), then B F must be slightly over 10 lbs. exerted obliquely downward instead of upward, as in the case of pulling, with the result that E F (3 lbs.) is now transferred from the man to the barrow. And if a cord were attached to the shafts at B it would be found, if tested by dynamometer or other means, that the force of 44·7 lbs. in the direction of B to H would in like manner produce motion to the barrow equal to the two forces B F and B G.

By drawing a line from the centre of the wheel at right angles to H B (continued), bisecting at K, then K A would equal 6·7, so that as K A (6·7):C A (2·5)::the load (120 lbs.) = B H (44·7). Therefore, *Fig.* 17 will represent the component and resultant forces as against *Fig.* 14, showing that in the act of thrusting the barrow the weight now carried by the man is 168 + 43·8 = 211·8 lbs. as against 217·8 in the act of pulling, or a difference of six pounds in favour of pushing on good level ground. But six pounds does not fully represent the difference, because, from the author's previous assumption, every pound of a man's weight or added weight, carried at the rate of four miles per hour, represents 2 lbs. at every stride due to the falling of his centre of gravity in the act of walking. Therefore, when the man has 6 lbs. more weight in one case than in the other, it means that he is also unavoidably suffering an increase of 12 lbs. percussion at every stride in the act of pulling, so that in a journey of 10,000 yards, or 30,000 feet, the man pulling will suffer $30{,}000 \div 2 \times 12 = 180{,}000$ lbs. more percussion on his feet and legs than the man who has sense enough to thrust his load. Thus, in 300 working days, or one year of his life, even with the above small difference, the latter saves his limbs from $(180{,}000 \times 300) = 54{,}000{,}000$ lbs. of percussion, besides all the energy which would have been required to have resisted it. It must be obvious that the more a man or a horse is burdened, no matter whether he be carrying or pulling a load, his strides will get shorter and shorter until he cannot effect a stride at all.

Now that which occurs with this simple vehicle and the man using it occurs with every vehicle hauled by horses, although the manner of the occurrence may often be unperceived by the ordinary observer. This is shown by reference to *Figs.* 14 and 17, and by means of the models exhibited.

The fact that so much has been, and is being, said upon the vexed question of the angle of draught is unmistakable evidence that when men speak of it they speak without the understanding which should come from personal investigation, freed from the trammels of custom. Because their forefathers attached their horses by traces hooked to fixed splinter bars or shafts, and since splinter bars have been fixed to carriages at various heights, which, with a given height of a horse at a given distance from the bar, gives a definite angle of trace, they continue to think that the only right way to proceed. To raise or lower the bar or to attach a larger or smaller horse is to alter the angle of trace and consequently the angle of draught. Therefore, a coach builder, in taking an order for a carriage, requires to know the height of the horse by which the carriage is to be drawn, so that he can determine amongst other things, at what height the splinter bar must be fixed. But builders entertain very different ideas as to what is the best height, or what is the best angle of trace. Some say the trace should be in a line with the horse's body; others say at an angle of 6°, some 11°, some 15°, 30°, and so on, and that the angle of trace is the angle of traction. Now the following will show that this confusion is the result of the want of the necessary insight into the application of the mechanical principles. Carriage, coach, and wagon building is still detrimentally affected by ignorance of principles that, in the light of the knowledge we now possess, we are inclined to think common-sense alone ought long ago to have taught. The poor horse is thus the victim of past ignorance on this vexed but yet now very simple problem.

From what has been said it will be readily understood that no one angle or draught can continuously be the right one, and that the necessary angle is an angle ever changing with the gradient and character of the road and at every stride of the draught animal. As an elementary illustration of this, reference may first be made to *Fig.* 18, which represents a man pulling a wheel loaded with 288 lbs.

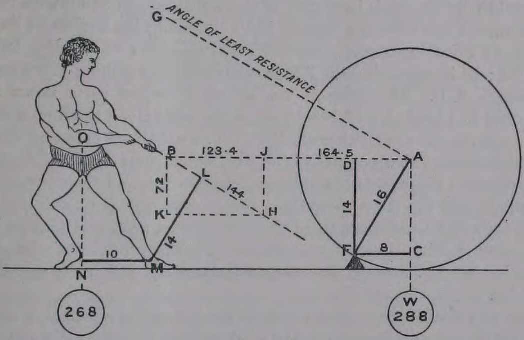


Fig. 18.

F represents an obstacle over which the wheel is to be hauled. It is obvious that the line of least draught will be in the direction A G, at a right angle to the line of resistance A F. A pull along this line A G of 144 lbs. will balance a load of 288 lbs. on the wheel at the point of rotation over the obstacle F, because the lever F A is double the length of F C. As, however, the man cannot pull along the line A G, but along a line A B, he necessarily pulls at a disadvantage, because the altered direction of force changes the leverage from that of F A (16) to F D (14), and consequently will now require a force of 164·5 lbs. along the line A B to cause the wheel to rotate over the obstacle. Then, again, since the pull is a horizontal one, the man's natural weight might not be sufficient to enable his muscles to exert the necessary power ; the load will thus have the mechanical advantage over the man. But it is a very simple matter to reverse this state of things, and to give the advantage to the man. This is done by taking some of the load from the wheel and placing it most conveniently upon the man, at least until he has effected the desired object. By so doing, it must be obvious to all that the man will thus get a two-fold mechanical advantage over his load, because (1) the load upon the wheel is reduced, whilst (2) he is temporarily made heavier, and thus capable of exerting a greater force, being practically made into a heavier and virtually stronger man. The importance of this applies just as much to the horse as to the man, as will be shown later. Now suppose we transfer 72 lbs. from the wheel to B (the man's hand) ; thus there will remain 216 lbs. on the wheel, and will requre a force of 123·4 lbs. along the horizontal line A B to raise the load. But the man will thus be exerting two forces ; he is supporting the 72 lbs. vertically, and pulling 123·4 lbs. through A B. Therefore, if we set off 72 equal parts down a vertical line from B, and 123·4 such equal parts along the line B A, and complete the parallelogram B J H K, we shall not only find that the diagonal B H will equal 144 of such equal parts or lbs. of force, but that the diagonal is exactly parallel with G A, and therefore, the resultant of the two component forces B J and B K will have precisely the same effect upon the man's body, arms and feet, as if he were pulling directly through A G. Therefore, the man in pulling 144 lbs. through A G would increase his weight by exactly 72 lbs.

A very similar diagram of forces to the one under notice was one of the author's original illustrations, which provoked much discussion and opposition some seven years ago. But, although it is now admitted to be correct, the above fact speaks volumes, and reveals a most remarkable misunderstanding of those mechanical laws which have existed ever since the world began.

In reference to horse power, the importance of taking into consideration all the forces which produce a certain effect when the load is placed in the rear or in the front of the axle must now be dwelt upon with reference to *Figs.* 19, 20, and 21. Let us first consider the conditions and the results when the load is placed at the rear of the cart, as in *Fig.* 19. We will assume that the lever constituted by the body and shafts of the cart will produce such a lift at the belly-band as to equal 10 lbs. at the point A or T. The lift at the belly-band must therefore be greater than 10 lbs., because the long arm of the lever from the centre of the wheel to point of back-band is shorter than to the point of the hame A. We must now understand what it is that the horse is doing. We know that if both the traces should break the load would run backwards down

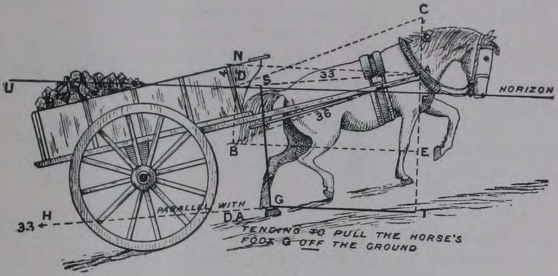


Fig. 19.

the hill. But as the load is kept moving forward up the hill, in spite of its tendency to run backward in obedience to the force of gravitation, we know that a counteracting force must be exerted by the horse through the traces. Inasmuch as we are also aware that the cart would tilt upwards at the shafts were it not for the influence of the belly-band, it must be clear that the horse is exerting a force not necessary to the mere pulling of the cart. He is holding down the shafts with a force at the belly-band equal to 10 lbs. at A.

Now let us suppose that he is exerting a force of 36 lbs. through A B in a line from the hame to the centre of the wheel. Then let A C represent the vertical depression necessary to hold down the shafts. Since A B and A C are the forces necessary to produce motion, by completing the parallelogram A C D B we find that A D represents the resultant of the forces A C and A B. Thus we determine one arm the lever, G S acting against G T, the other arm. G S is a line drawn at right angles from the direction of force A D.

The author wishes to make it clear that if the load had been balanced on the axle, then, regardless of the angle of trace or hame-chain, the virtual angle of draught exerted would be through A B to the centre of the wheel. Then a line at right angles with A B to G would have been the short arm of the lever, which would have enabled the horse to have pulled a much greater load than possible by the longer arm G S. But due to the load being behind the axle, the forward weight of the animal is reduced by the lift of the shafts at point A, and the result is the same as if the traces had been put up at the point D, and the load, with a 33 lb. pull through such a trace, would be exactly balanced, and no lift at that moment would be exerted at the belly-band ; neither would there be any depression at the back-band, although the trace would be so much above the centre of the wheel. In other words, the tendency of the load to rotate backward would, by such a trace (A D with a 33 lb. pull), be counteracted. There would be equilibrium, and the horse, so far as his power to pull is concerned, would be acting under the same conditions as though he had the lift at the belly-band and his trace at the centre of the wheel.

A resultant pull of 33 lbs. through A D is equal to the thrust on the horse's hind foot in the direction H G, tending, as will be observed, to draw the animal's foot off from, instead of into, the ground, thus causing him to slip sooner than if the resultant had been either parallel with the road, or, especially, if it had been digging into the ground. This resultant ought now to be treated as a component, together with the horse's natural and added weight on hind feet, due to the pull and the gradient. Let U V represent the horizon passing through the point D. If D A represents 33 lbs., then F A will represent 4 lbs., so that 4 lbs. must be added to the horse's natural weight by the pull A D. Or, if the pull through the trace A B is 36 lbs., then, drawing B E parallel with the horizon U V, E A (14 lbs.) will represent the depressing force due to a 36 lb. pull through A B. But when the lift due to the shafts (10 lbs.) is deducted from the 14 lbs., there remains, as before, an increased weight of 4 lbs on the horse.

But when the same horse is pulling with the same force upon a level, as in *Fig.* 20, we find that the results are very different from those when pulling upon an incline. Let P A be the direction from the hame to the centre of the wheel, and represent a 36 lb. pull. Assuming the load to have been moved further to the rear, the lift at the belly-band is still 10 lbs. at P. The load is moved backward to shift the centre of gravity. The resultant of the two components P A and P B is P C, and P C now equals about 35·9 lbs., whereas the resultant A D in *Fig* 19 is only 33 lbs., or 2·9 lbs. less than on the level. It will now be found that 36 lbs. pull through P A will increase the horse's weight 4·5 lbs., represented by P O, which is determined by drawing A O from A, parallel with the horizon, cutting the line of gravity P E. But as the disposition of the load is such that 10 lbs. are taken from the horse, it is obvious that if only 4·5 lbs. are put back by the said pull of 36 lbs., the horse has still 5·5 lbs. less than his natural weight in *Fig* 20, while in *Fig* 19 he has 4 lbs. more than his natural weight.

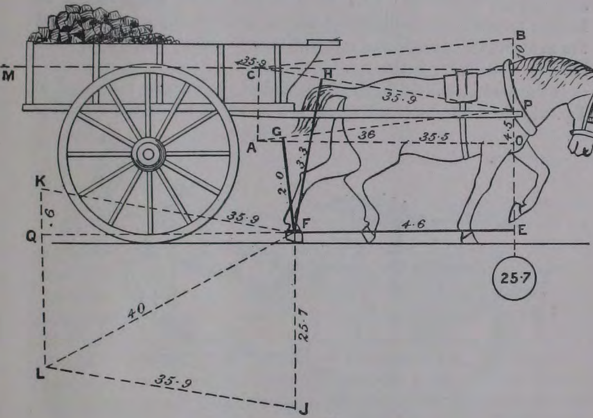


Fig. 20.

It is essential that we should know why this difference is brought about; otherwise, we should not know why horses have greater difficulty in climbing hills with loads than travelling on the level. Neither could we have an intelligent idea how to mitigate the evil, or how to assist the animal in the duties he is called upon to perform. In all cases it is absolutely necessary that we should know not only the pull through the trace which the horse is exerting, but we must know the exact force exerted by the animal, either through the back-band or the belly-band, according to the disposition of the load. The one or the other of these forces is of just as much importance as the pull through the trace, and yet, strange to say, they have been practically ignored in the past, with lamentable results.

Inasmuch as these forces are continually changing, due to the inequalities of the road over which the horse is travelling and to the strides of the horse, they must not be considered as constant, although no perceptible change is taking place. They exist momentarily, varying in proportion to the irregularities of the roadway or the unsteadiness of the gait of the horse. These irregularities intensify and diminish the lift and depression very much for and against the horse; to such a degree, even, that, should he happen to get his propelling foot upon a hard or slippery surface at the moment when the forces referred to are against him, he slips and receives a strain, or is thrown.

If the load be shifted to the front end of the cart, as indicated in *Fig.* 21, the resultant of the forces P J and P K lie in the direction

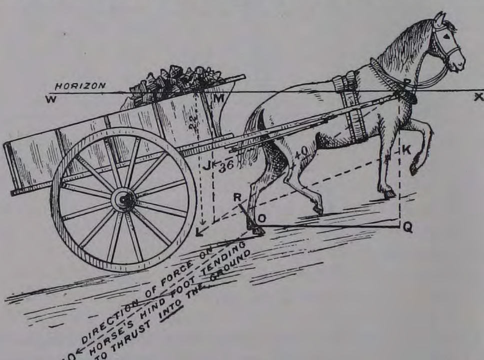


Fig. 21.

of P L, and the added weight on the horse is 22 lbs., instead of 4 lbs. as in *Fig.* 19, tending to thrust his hind foot into the ground at O, and he exerts a pull of 40 lbs. as against 33 lbs. under the conditions indicated in *Fig.* 19.

A word now as to the resultants when pulling up a gradient and on a level plain, the latter being soft or stony ground, requiring exactly the same pull through the trace as when climbing the gradient. It will be observed in *Fig.* 19 that the point of application of force A (the hame) is above the horizontal line U V, drawn through the point D, this being the point at which the traces might be fixed with an advantage equal to having them attached to the axle when the given lift is exerted at A, with a lift at the belly-band as set forth; whereas P, the point of application of force in *Fig.* 20, is now much below the horizontal line M N, drawn through the point C on the resultant or virtual line of draught. Therefore, if we now compare the triangles of force A B E (*Fig.* 19) and P A O (*Fig.* 20), we shall find a great difference. A B and P A represent the pull through the traces, and, inasmuch as they are not at the same angle with the horizon, although the force in such is precisely the same—viz., 36 lbs.—the result upon the horse is quite different.

If A B in *Fig.* 19 represents a 36 lbs. pull, and A C a 10 lbs. lift, then A D (33 lbs.) is the resultant direction of force applied by the animal. Now it will be found that a 36 lbs. pull through A B, together with a lift of 10 lbs. through A C, or a pull of 33 lbs. through A D, will both be effective in lifting 2·5 lbs. from the horse's fore-quarters.

The question has been asked, "Should the horse support the vehicle, or the vehicle the horse?" The author will refer to the cyclist in answer. It is obviously clear to all that the man can travel very much farther and easier when riding his machine than if he were to walk and carry it. In like manner, on similar roads, where resistance to traction is small, it is equally easy for the horse if at such times the vehicle is made to carry as much of the horse's weight as possible. But while it is clearly right for the bicycle to carry the man on a hard level road, yet the condition and the inclination of the road might be such as to make it actually necessary for him to get off and carry a part or the whole of his machine. The same principle will apply to the horse and his load. Consequently, in order to economically utilize the power of horses, it is highly essential, in fact, necessary, that we should cause them to labour in accordance with the dictates of common-sense and natural law, giving them, as far as possible, those conditions which conduce so much to our own ease and comfort.

It has now been proved by practical every-day tests, in various parts of the country, extending over a period of about four years, that very considerable relief can be mechanically afforded to horses in the performance of their arduous duties; and that they cannot only be enabled to do more profitable work daily, but that their useful lives can be very nearly, if not more than, doubled. This can only be done by some automatic contrivance to four and two-wheeled vehicles as will automatically cause the horse to carry a part of his vehicle at one time, and that the vehicle shall carry a part of the horse at all such times as that the resistance to traction shall permit.

The author will now show by what means the automatic change of the virtual angle of draught can be made in the case of a four-wheeled vehicle, and how the limbs of the draught animal, which are at present most severely wrought, can be very greatly relieved. This is illustrated by *Figs.* 22 to 26.

Fig. 22 will enable the author to explain the simple mechanism by means of which the horse is enabled to automatically increase his

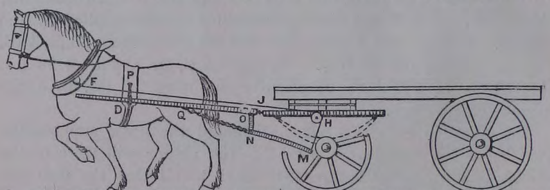


Fig. 22.

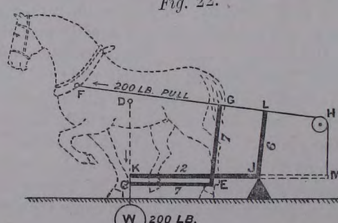


Fig. 23.

weight by his own pull. J is the splinter-bar of an ordinary fore-carriage, on which the shafts J D are hinged. The bent extension arm M N O is pivotted at or about J with chain connecting the extension arm to the shafts at Q, so that the arm and the shafts shall become a lever with its fulcrum at J.

The trace passes from the collar F over the pulley H, and attached to M. Therefore, whatever pull is exerted at F, say 200 lbs., there will be a corresponding lift at M, and since the arm M J is only half the length of J D, there will be a downward pressure of 100 lbs. at D resisted by the horse's back. Thus it will be seen that the animal's forces are distributed over the muscles of the shoulders and of the back. But if the horse were compelled to work at all times with such a contrivance he would be continually carrying a part of his load, as in *Figs.* 2 and 6, with the consequent loss of life and energy. This, however, is avoided by the aid of springs, to which special attention will be given after reference has been made to *Fig.* 23, showing perhaps more clearly how the horse brings weight automatically upon himself. Let the bent lever C E G (*Fig.* 23) represent the lever constituted by the horse, and be equal to the bent lever C F P in *Fig.* 11. If the force W (200 lbs.) at C is not sufficient to exert the necessary horizontal force at G as was shown in *Fig.* 11, then, by bringing into play a second straight or bent lever K J M or K J L, with its fulcrum J fixed by any means to the vehicle, and pass a trace from G over pulley H to M,

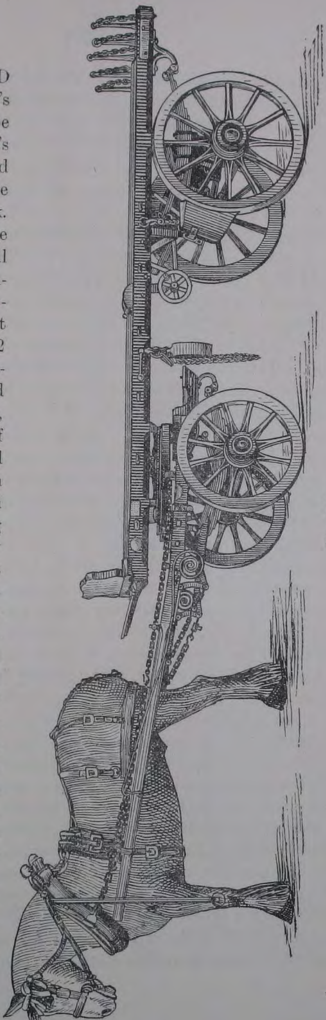


Fig. 24.

or from G to L, it will be readily seen that, since J L or J M is half the length of J K, if 200 lbs. be exerted at G and transmitted to M or L, then 50 lbs. must be added to C by the pressure of K, with the result that motion will be effected to a greater load by decreasing the weight of the load, and simultaneously increasing the weight and power of the motor horse, which thus procures a two-fold mechanical advantage.

Having thus explained the importance of added weight to the horse whilst starting, or pulling, heavy loads up hill, the author would now particularly emphasize the still greater importance of causing the said levers to automatically support and carry not only the weight of the shafts, but also a part of the horse's own weight at all such times as when the pull through the trace is comparatively small. Thus the same ease and comfort is given to the horse as is obtained by the coster when he leans on his cart, or the nurse-maid upon her perambulator, which will in like manner enable the horse to travel further and easier with the vehicle than he could possibly travel without it. This important feature is secured by coiled, tempered, round, steel spring, with extended arms reaching well up the shafts and hooked thereto, as will be seen by reference to *Fig.* 24, which is taken from photograph. These springs are sufficiently strong to bear the total weight of shafts from the horse's back, and to support from 20 to 100 lbs. of the horse's own weight. Let us assume the shafts, at the point of back-band, to weigh 100 lbs. (many weigh considerably over that), and the horse is relieved of this, and of, say, 50 lbs. of his own weight; thus, according to what the author has already shown, the horse must suffer less percussion in his legs and feet by $100 + 50 \times 2 = 300$ lbs. per stride. Therefore, the saving in percussion alone in one day's journey of 14 miles (at 4 miles an hour) will represent, roughly, $1,760 \times 3 \times (14 \div 2) \times 300 =$ 11,088,000 lbs., or in one year of his life, at 300 working days, he would save $11,088,000 \times 300 = 3,326,400,000$ lbs. of percussion. But this is not all; he will save millions of pounds of force which would otherwise have to be exerted to overcome the ground resistance. Under these circumstances, knowing how our horses are burdened by being compelled to carry absolutely unnecessary weight upon their legs and feet, can we wonder at 90 per cent. of them failing first in these parts, whilst their constitutions are practically sound? Although the lift effected by the springs is so beneficial over about seven or eight-tenths of the horse's journey, it would prove a very serious thing for him when starting or climbing hills, if it were not for the automatic counter-action of the mechanism set forth in *Fig.* 22. The lift is converted into a depression, or it may be merely reduced according to the pull exerted through the traces. Thus it will be understood that the attachment is so contrived that the horse's own increasing pull to overcome resistance will automatically do all that is required either in merely reducing the maximum lift or converting it into a large depression, as, and only when, required. Thus he will be able to deal effectually with heavier loads and continue to live and work for many more years.

The same principles apply just as much to the haulage of tramcars. The fact that these vehicles run on rails does not in the least relieve horses from their greatest source of premature destruction. *Fig.* 25 is a side elevation of a single-horse tramcar attachment. For a pair of horses the single attachment is simply duplicated, and each horse is left to work free from the action of his companion. Horses suffer loss and fatigue by being coupled to the same swingle trees, as is the case with two persons walking arm in arm when out of step with each other.

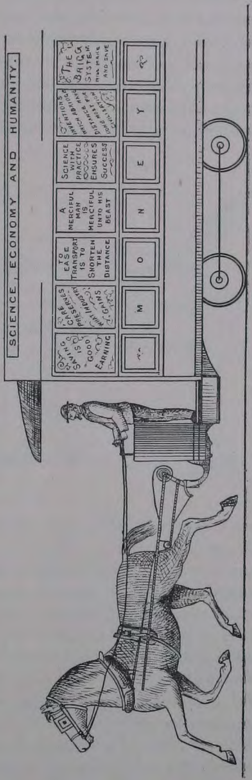


Fig. 25.

A very much greater percentage of horse power can be saved with tramcars than with any other road vehicle in common use. To enable one horse to do as much profitable work as two have been accustomed to doing will be a very simple matter, and from a humanitarian aspect it is possible to confer upon beasts of burden an unspeakable relief from the miseries which have hitherto been so unconsciously imposed.

With a two-wheeled cart it is impossible to give the horse that automatic adjustment of the load which can be so advantageously given with a four-wheeled wagon. The author was often asked by General Sir Redvers Buller about the application of some attachment to two-wheelers. After much thought, it was seen by the author that the object would be attained by attaching a trailing fulcrum, supported by a third wheel, as shown in *Fig.* 26, and that by this

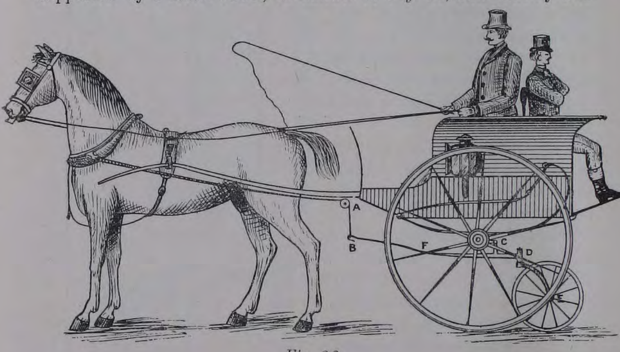


Fig. 26.

means the horse will automatically secure those conditions which will enable him to start his load easier, save his legs and feet by being partially carried on good roads, and enable him to secure the necessary mechanical advantages over his load when pulling up-hill. *Fig.* 27 shows the attachment on a hansom cab, where there is no means of moving the seats or the load forward when climbing hills, except that the occupants will sometimes lean forward and the driver will stand and lean over his cab. In this case the trace is continued over pulley F, under pulley E, and from thence to hooks C of the attachment.

The resultant of a 90 lb. pull through the trace with this attachment is obtained by the aid of the parallelogram J F H K. Let J F equal 90 lbs., therefore the force through F E must equal 90 lbs., represented by F H, and by completing the parallelogram we find the resultant K F equal to 71 lbs. upon F in the direction of F K. Then by producing K M (direction of force) to M, we find that 71 lbs. must be exerted upon a lever, which the cab itself constitutes, equal to M Q against a second arm Q and N, since Q M is only half the length of Q N, then a pull of 71 lbs. at M will equal a 35·5 lbs. transfer of force at N, or 42·1 lbs. at R S, the horse's back-band.

The bodies of all two-wheeled vehicles should be mounted further back upon their axles when the attachment is applied, so as to relieve the horse's back and limbs from the serious consequences produced upon them, due to percussion and exhaustion. *Fig.* 28

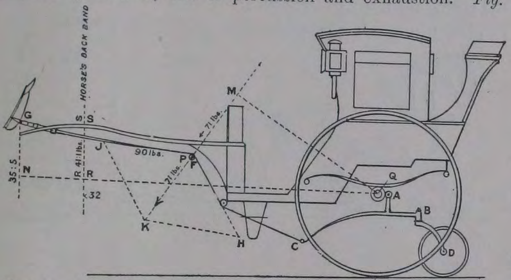


DIAGRAM OF FORCES EXERTED IN HAULING HANSOM CAB WITH THE BRIGG ATTACHMENT.

Fig. 27.

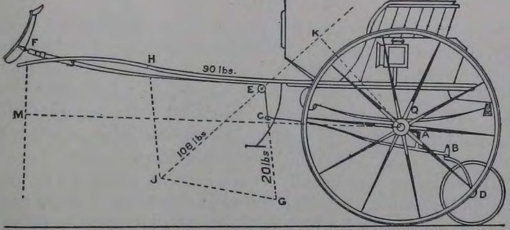


DIAGRAM OF FORCES EXERTED IN HAULING GIG.

Fig. 28.

shows the lever D B A C with pivot at B, to allow the vehicle to be turned anyhow, regardless of the trailing wheel. In this case the trace passes from the horse's collar over the pulley E, and is attached by a hook to the end of the lever at C. Thus, if the horse should pull H E (80 lbs.) through the trace he will produce E J (a resultant of 100 lbs.) acting obliquely downward. Extend the line J E beyond K; draw line from A at right angles with J K; then K A represents one arm of a lever constituted by the body of the cart, whilst a vertical line from F and a line at right angles thereto from A will give M A the second arm of that lever; and, therefore, as M A is to A K, so is 100, will equal the transfer of weight at F when the upward lift—whatever that might be, due to the tilting tendency of the load—has been deducted therefrom.

Fig. 29 is one of several diagrams specially prepared by the

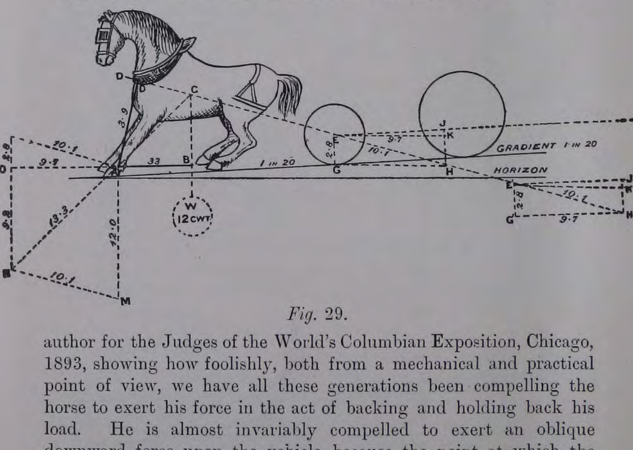
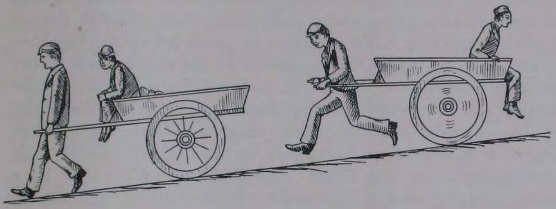


Fig. 29.

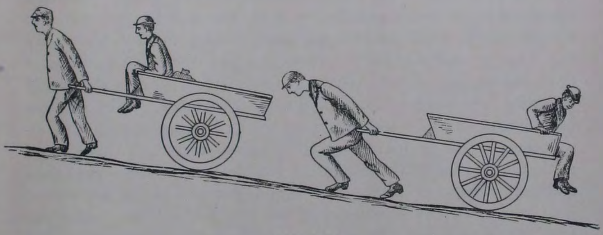
author for the Judges of the World's Columbian Exposition, Chicago, 1893, showing how foolishly, both from a mechanical and practical point of view, we have all these generations been compelling the horse to exert his force in the act of backing and holding back his load. He is almost invariably compelled to exert an oblique downward force upon the vehicle, because the point at which the shafts are attached to the vehicle are lower than the centre of gravity of his own body; consequently he is practically compelied to partly sit upon the vehicle, increasing the weight upon the wheels, and at the same time decreasing his own weight and his power to thrust or hold back; thus he labours under a two-fold mechanical disadvantage. To exert a force of 10·1 cwts. through C E will be effective in transferring G E (2·8 cwts.) of the horse's weight from his own feet on to the wheels, whilst only 9·7 cwts. would be exerted horizontally backward. The horse is thus compelled to exert his force under the same unfavourable conditions as are imposed in *Figs.* 12 and 19. Why is it that we in this practical and scientific age should so foolishly continue to waste that energy which is generated in the animate locomotive, *the horse?*

In conclusion, the author would draw attention to *Figs.* 30, 31, 32 and 33, which are practically a repetition of *Figs.* 1 to 7. These



Down Hill.

FOOLISH. *Fig.* 30. WISE. *Fig.* 31.



Up Hill.

WISE. *Fig.* 32. FOOLISH. *Fig.* 33.

illustrations of the principles involved in the haulage question are so simple and self-explanatory to any ordinary mind that it will almost be impossible, even for the most sceptical, to doubt that those conditions which are BEST and *wisest* at one time are the worst and most *foolish* at another. So much so, that *Fig.* 31, with the load at the rear of the cart, would travel three or four times further, down a slight grade or on the level road, in a day than *Fig.* 30. But in the case of climbing a stiff hill, then *Fig.* 32, with the load at the front of the cart, would be able to travel three or four times further per day than *Fig.* 33. Those *mechanical conditions* which conduce most to the comfort and to the power of endurance of man, either in the act of self-locomotion or in the transport of goods from place to place, are the *precise* conditions which conduce to the comfort and to the power of endurance of the horse, and yet there is not a single institution in the world, to the knowledge of the author, where the fundamental principles of economy in animal haulage are either taught or understood. Mechanical textbooks have created such false impressions in the minds of students that when they have become men they seem to cling to these impressions like grim death, and are thus prevented from realizing the true state of extravagance and cruelty which consequently exists, to the loss of every civilized country under the sun.

Whilst the scientific world has so ignored the mechanism and right use of the horse as the largest and most useful transport agent ever used, it is strange that there has never been a great poet who has not paid one of his finest tributes to the beauty, courage, intelligence, generosity and fidelity of the horse. In fact, there are no grander or more sublime passages written in any book than the grandeur and sublimity of those in which the noble qualities of the horse are pourtrayed. Great generals have wept over the loss of favourite horses as for faithful and departed friends. The greatest have honoured their remains with tombs bearing appropriate inscriptions. He is found in all history—sacred, profane, and modern—sharing in the conquests and defeats, in the occupations and amusements of man. For untold generations he has served man, performed the drudgeries of his life, and *yet* how badly the majority of men and neglectfully scientific institutions have treated him in return for the noble services which he has done toward the prosperity and civilization of this and other countries. He has been handicapped in the performance of his work to an almost indescribable extent; give him simple justice, and he will continue to serve you as few motors can. If the author of this paper should have succeeded in explaining to the satisfaction of his hearers the *rationale* of a great deal that has been more or less obscure on the questions of draught and haulage, and if he has said enough to awaken the interest of engineers and horse-owners to the importance of the vast fields of research and profit which are open to them, not only as it concerns the economical employment of horses, but as it affects the employment of any forces used for haulage or transport purposes by any means, then he, too, will be satisfied.

PAPER IX.

LIGHT RAILWAY CONSTRUCTION.

By E. R. Calthrop, Esq., C.E., Liverpool.

Theory of Narrow Gauge Light Railways.

The traffic to be carried in any district, through which a railway is about to be constructed, is the same whether the proposed railway be built on the standard gauge, or on a very narrow gauge ; but the revenue, which might result in an actual loss on the working of the former, may be made to produce a satisfactory return on the much smaller capital of the latter. The object aimed at by the advocates of light railways of very narrow gauge is the provision of railway communication on a remunerative basis, in countries and districts where the traffic to be carried is considerable, but insufficient to produce a proper return on the capital required for a railway of normal type.

To attain this object the fundamental idea of light railway construction and working is the elimination of every kind of expenditure which is non-essential to its efficiency as a means of transport, and the reduction of all permanent way, plant, and appliances to their simplest and most inexpensive forms.

The reductions in cost of permanent way, obtained by the use of lighter rails and smaller sleepers, are supposed by many to be the only advantages offered ; but while the gains under these heads are not inconsiderable they are really the least of all. The principal savings in capital cost, effected by narrowness of gauge, occur through the much greater flexibility of its alignment as compared with that of the wider normal gauges. The established minimum radius of curves, on open line and in sidings or difficult country, is for the several gauges respectively as follows :—

Minimum Radius of Curve (Indian Practice).

Gauge.	Ft.	In.	Radius in ordinary country. Feet	Radius in sidings or difficult country. Feet
Standard	5	6	1600	600
Metre	3	$3\frac{3}{8}$	1000	400
*Special	2	6	250	150
	2	0	150	60
Minimum Radius of Curve (English Practice.)				
Normal	4	$8\frac{1}{2}$	1320	462 to 660
			=20 chains	=7 to 10 chains

The small radius of the curves of the narrowest gauges confers immense advantages in locating the alignment of a light railway. Its flexibility permits it to wind in and out to avoid deep cuttings, heavy embankments, and the severance of valuable property, and, if required, to follow all the convolutions of an ordinary road. Tunnelling, heavy rock cuttings, and steep gradients can often be avoided by a quick detour quite impossible on the standard gauge; the latter by the greater stiffness of its alignment is often compelled to plough through buildings and other valuable property, and to construct bridges and other expensive works, which otherwise might be avoided. The extraordinary cheapness in capital cost of the 2ft. 6ins. gauge lines built in India is explained chiefly by this avoidance of costly obstacles, and the utilization of long reaches of ordinary roads which Government has permitted them to use free of cost.

Compared with the *possibilities* of standard gauge rolling stock,

* In the new regulations of the Government of India relating to standard dimensions to be observed on 2ft. 6in. and 2ft. gauge railways in India, the minimum radius permitted on main line is 238′ = 24° angle of curvature, and 204′ = 28° angle of curvature respectively, but in open country a radius of 1,432ft. is recommended for both.

the cost of carriage stock per passenger seated, and of wagon stock per ton of load, is somewhat less. As compared with the standard gauge wagon stock *actually in existence*, the cost per ton of load is very considerably less. The cost of locomotives per ton weight and per indicated horse power is, as one would expect, rather greater on the narrow gauge.

In designing the permanent way and rolling stock for a narrow gauge light railway, the principal object to be aimed at is to obtain the greatest proportionate traffic capacity, from the cheapest possible track. Everything must be made subsidiary to the cheapening of the track. Any additional costliness of the rolling stock, as will be shown later, is as nothing if it results in any considerable reduction of the weight, bulk and cost of the track.

On any kind of railway, the cost of track must be the principal consideration, for it is obvious that, if it is possible to quadruple the length of the track for the same expenditure of money, by so doing the traffic area of the line is also quadrupled. In other words, a narrow gauge light railway, laid down at one-fourth the cost of the standard gauge per mile, is sixteen times more efficient as a revenue producer, than a standard gauge line costing the same amount, by means of its being four times as long and carrying four times the traffic over the additional length. I am speaking, of course, of conditions where the traffic is an even quantity and proportional throughout to the length of the line, and where the cost per mile is fairly even throughout its length. Such conditions, from a variety of causes, are comparatively rare in England, but in other countries, possessing large areas unoccupied by railways, they are by no means unfrequent.

It follows then, under these conditions, that a very narrow gauge line being able, with the same expenditure of capital on track, to earn sixteen times the revenue of a standard gauge line, it can afford, theoretically, to run through country so poor that it produces but one sixteenth of the traffic that would be necessary to obtain a remunerative return on the capital of a standard gauge line if constructed through the same country.

After what has been said it is hardly necessary to point out that the prospects of any light railway improve directly with its length. The longer the run the greater the traffic and the cheaper it can be worked. If a light railway, constructed at a minimum cost per mile, should not make an altogether satisfactory return on capital, the surest remedy is to extend it.

Demonstration of the Correctness of the Theory.

How is this theoretical superiority of narrow gauge lines as dividend earners borne out in practice ?

In India as is well known there are now four gauges : The Standard 5ft. 6in. ; the Metre 3ft. $3\frac{3}{8}$in. ; and two Special gauges, the 2ft. 6in. and 2ft. 0in. In these last days of the century with the results of 60 years of railway progress behind us, it is difficult to understand the failure 50 years ago of the Government of India to appreciate the certainty of the linking up of the European and Indian Railway systems, which is now on the threshold of events. The original gauge, unfortunately selected as the standard for India, was the 5ft. 6in. At a latter date it was discovered that the costliness of the 5ft. 6in. gauge was an absolute bar to the extension of railway communication in certain of the poorer districts of India, and after much agitation and consideration the metre, or 3ft. $3\frac{3}{8}$in. gauge, was eventually sanctioned for lines, which were held to be of minor importance strategically, with results which generally fully bore out the anticipations of their supporters.

More recently again attempts were made to obtain a still cheaper form of railway in districts where even the metre gauge could not be laid down remuneratively, with the result that after a still greater resistance on the part of the authorities a number of short lines have been sanctioned and constructed on the 2ft. 6in. gauge.

There is perhaps no country in the world where railway statistics are as carefully registered and collated as in India, and there is certainly no more interesting production published by any Government than the Administration Report on the Railways in India, which is characterized by intelligent analysis and extreme accuracy.

In this Report statistics of the working of the standard, metre, and special gauges are dealt with separately, so that I have been able to represent the general results of the working of all railways in India grouped according to their gauges. The subjoined table, in which the ultimate influence of gauge upon capital cost, working expenses, and net profits is shown to be of a most remarkable character, affords the completest justification of the policy of the Secretary of State in anticipating the recent legislation in England by permitting the construction of railways of a smaller gauge than the normal, in districts where the traffic is insufficient to support a railway of standard type.

General Results of the Working of all Railways in India, for the Year Ending December 31, 1895.

Particulars.	Standard Gauge 5′ 6″	Metre Gauge 3′ 3⅜″	Special Gauges 2′ 6″ & 2′ 0″
Capital Cost.			
Average cost per mile open ... ...Rupees	1·58,730	71,121	32,950
Ditto at Exchange, 1/3¼	(£10,095)	(£4,519)	(£2,093)
Passengers.			
Passenger unit miles, per mean mile worked ...Unit-miles	368,456	264,351	93,943
Average distance of journey ... Miles	41·9	37·6	27·1
Goods.			
Goods, ton miles, per mean mile worked ... Ton-miles	358,028	124,511	16,364
Average distance carried ... ... Miles	156·1	119·2	34·1
Working Expenses.			
Percentage of working expenses on gross earnings, per cent.	45·14	49·12	53·16
Net Profits.			
Percentage of net profits on total capital outlay on open line, per cent.	5·78	5·73	7-67

The facts disclosed by the figures as they relate to the three gauges are as significant as they are unimpeachable. As compared with the average cost of the standard gauge, it is shown that the average cost of a metre gauge line is rather less than one half, while the cost of a 2ft. 6in. gauge line is actually only one-fifth. It should be also noted that with a difference of only 9⅜ins., the metre gauge is more than twice as costly as the 2ft. 6in., although in ultimate traffic capacity the difference between these two gauges is extremely small. These figures include rolling stock and all capital outlay whatever. But taking into consideration the circumstance that when the older standard gauge lines were built there was a higher range of prices for rails and rolling stock, we are nevertheless face to face with the fact that for the same expenditure of money it is possible to construct and equip 400 miles of 2ft. 6in. gauge at the cost of 100 miles of standard gauge. In India at all events it is not open to doubt that a line of narrow gauge, carried to a distance of 100 miles, must produce, in its combined capacity as a feeder to the main trunk line, and as a distributor of English merchandise, a much greater effect upon the development of an unopened district than a standard gauge branch of 25 miles, with 75 miles of cartage behind it. The extra length of the line secures for the benefit of the country much cheaper carriage, and for itself a much greater traffic catchment area. The cost of transhipment at the junction with the main line, which however can be altogether avoided by an appliance about to be described, is as nothing compared with the saving effected in the cost of carriage over the additional 75 miles of line which can be laid for the same money.

The next and most important result which the table makes clear is that the 2ft. 6in. gauge running through the poorest districts, for short distances only, with a passenger traffic per mile of less than *one-fourth* that of the standard gauge, and with a goods traffic per mile only *one-twentieth* that of the standard gauge, is not merely able to survive, but can actually show a greater percentage of net profits on total capital outlay than the standard gauge trunk lines running through the pick of the country, and backed by all their great volume of arterial traffic carried over long distances. The above results illustrate in the most practical manner the concrete effect of the multitude of small advantages gained by the adoption of a very narrow gauge, and fully demonstrate the correctness of the claim made for it that such a line is able to run with satisfactory financial results through country producing but a very small fraction of the traffic required to obtain a reasonable return on the capital of a standard gauge line.

It is as well to point out that there is a great principle underlying the question of gauge: *A railway is a machine, and, like any other machine, is economical only when working within a reasonable measure of its full power.* In the recognition and observance of this principle lies the whole art and mystery of the financial success which has attended the working of narrow gauge lines on the Continent and in India, in districts where a standard gauge line would not only starve, but would lose money to the end of the chapter.

History of the Barsi Light Railway.

The main points in the history of the Barsi Light Railway may be of interest to you as exemplifying the difficulties which have attended the introduction of Light Railways in India, and of this project in particular.

The Barsi route, as the main line of traffic the between dominions of His Highness the Nizam of Hyderabad and the Port of Bombay, has existed from time immemorial. Previous to the construction of the Great Indian Peninsula Railway the traffic was carried down to Bombay in bullock carts and on pack animals. In the yeaı 1856 the existing rough cart track was converted into an unbridged and roughly ballasted road with the result of a great increase in traffic. After the construction of the South East branch of the Great Indian Peninsula Railway in 1860, the traffic increased further to an average of 500 carts daily. In 1862 proposals were submitted to the Government of Bombay by the Chief Engineer of the Bombay Presidency for the construction of a bridged and embanked road to be traversed by a light railway. In 1870 the road and bridges were constructed, but the Government of Bombay did not find themselves in a position to incur the cost of the light railway. The improved condition of the road was followed, however, by a further great increase in traffic. In 1878 the Government of Bombay proposed to the G.I.P. Railway that a branch line to Barsi should be constructed as an extension of their system, and surveys were made in 1880 and 1881; but after all preparations had been made the Secretary of State finally informed the Company that he was "not disposed to enlarge the operations of the Company under any arrangement which would involve any extension of the guarantee of interest, or of the grant of pecuniary assistance to the Company from the State in any shape." The project of the branch as an integral portion of the G.I.P. system was therefore abandoned. A subsequent proposal that the line should be constructed by Government as a provincial railway, and worked by the G.I.P. Railway was introduced in 1882 by the Government of Bombay, and abandoned in 1885 with a notification that since Government found itself unable to advance the capital required the line should be undertaken by private enterprise.

In 1887, being Assistant Locomotive Superintendent on the G.I.P. Railway, I undertook a preliminary survey, and having satisfied myself as to the prospects of traffic, applied to the Government of Bombay for the concession to construct a line along the existing road from Barsi Road Station on the G.I.P. Railway to the town of Barsi, a distance of 22 miles, on the 2ft. 6in. gauge, without any guarantee of interest. The negotiations with Government were continued without intermission from March, 1887, until July, 1895 —a period of more than 8 years—during which I arranged three times for the capital required and expended £6,300 in surveys, estimates, and two special visits to India, involving together an absence from England of two years and ten months. It has been an experience which I do not wish to repeat, and although no guarantee or financial assistance whatever had been asked for, it cost over £260 per mile of line merely to obtain the concession on these terms.

In looking back on these protracted proceedings my pleasantest recollections are of the help extended to me by the Consulting Engineers to Government, and of others who were in entire sympathy with the system which I advocated. Without their energetic assistance it would have been impossible to have overcome the influential obstruction which then existed. It is pleasing, however, to be able to state that the resistances have now disappeared, and that the much talked of "encouragement of private enterprise," which for many years had been a mere snare and a delusion, is now becoming an accomplished fact.

Traffic on the Barsi Light Railway.

Before proceeding to describe the nature of the permanent way and rolling stock which I have designed for the Barsi Light Railway, it is desirable to give you an impression of the amount and character of the traffic to be accommodated. We are putting a small feeder line into a tract of country as large as the whole of England and Wales, which up to the present is totally unprovided with railway communication of any kind. The town of Barsi is the central mart of the trade to and from the great expanse of territory in the valley of the Godaveri belonging to His Highness the Nizam of Hyderabad, which territory is cut off from any access to the G.I.P. Railway for nearly 100 miles by the rivers Bhogavati and Sina, except through Barsi. Complete records of the traffic received at the Barsi Road Station have been kept for many years, as also of the traffic passing through Barsi town. For the five years ending December, 1894, the average goods traffic at Barsi Road Station passing over the

G.I.P. Railway amounted to 77,599 tons per annum, of which 95 per cent. was estimated to pass through Barsi town, an estimate which agrees with the municipal records. Since the year 1881, the first of which I possess complete records, the largest traffic occurred in 1891, the amount being 107,000 tons, and the smallest in 1888, the amount being 51,000 tons. The import traffic from Bombay averages one-third, and the export traffic from Barsi two-thirds, of the total tonnage. The extent of the area served by Barsi as a centre of distribution will be better realized from the fact that the average weight of salt imported, for human consumption alone, during the above mentioned five years, exceeded 7,000 tons annually. Other imports than salt consist chiefly of iron and other metals, machinery, mineral oil, silk and cotton piece goods, and twist and other European products. The principal article of export is cotton, of which the output in several seasons has exceeded 90,000 bales of cotton of $3\frac{1}{2}$ cwt. each, pressed at Barsi. The remaining exports are wheat, linseed, ground-nuts, native food, grains of all kinds, gingelly and other oil seeds, indigo, dyes, sugars, spices, wool, hides and skins. The passenger traffic, including pilgrims, over the road traversed by the light railway amounts to about 200,000 each way per annum.

The means of transport between Barsi and the G.I.P. Railway has been entirely confined to bullock carts carrying from 6 to 12 cwt. each, according to the nature of the goods. In the busy season 1,000 to 1,500 carts leave Barsi daily for the station. Beyond Barsi bullock carts are employed where the roads are fairly good, but pack animals carrying from 1 to $2\frac{1}{2}$ cwt. each are still used to some considerable extent.

The Barsi Permanent Way.

In the selection of the most suitable gauge for the Barsi Light Railway many considerations had place. It was essential, in view of the very large existing traffic and of its subsequent expansion, that its ultimate traffic capacity should be very great. On the other hand it was equally necessary that the cost per mile of permanent way should be so small that it would pay us to extend the line into localities where the traffic was comparatively insignificant, and that we should also be in a position to offer special siding accommodation with considerable generosity. It is accommodation and convenience which attract traffic nowadays, and the ability to run sidings at a comparatively trifling cost, into the cotton presses, warehouses, godowns, and compounds so as to eliminate all avoidable handling and cartage, all tends to develop trade and increase the traffic over the main line itself. These and the considerations enumerated at the beginning of this paper, originally led me to select the 2ft. 6in. gauge as the best for the purpose, and the more I know of it the better I like it. There is no doubt that as compared with all others it is the gauge possessing the *greatest carrying capacity per cent. of cost of track.* It has sufficient stability to carry goods of very great weight and bulk, while the flexibility of its alignment is such that it can accommodate itself to country of the most mountainous and difficult character, at a fraction of the cost of a standard gauge line negotiating similar difficulties.

After selection of gauge the next point was the minimum weight of rail and maximum load to be placed upon it. This, with the concurrence of the Secretary of State for India, I fixed at 30lbs. per yard and $2\frac{1}{2}$ tons respectively giving a maximum load of 5 tons per axle.* On the length to Barsi town the weight of rail actually laid down is 35lbs., but this has been purely a matter of economy in maintenance under an extra heavy traffic. For branches or sidings where the traffic is comparatively light we have utilized the 30lb. rail only.

In the 30 and 35lb. Barsi sections the head of the rail is of the same width, the extra metal in the latter being put principally on the top of the head. Fish plates and fish bolts are identical for both sections of rail. The head of both rails is made particularly wide with the object of providing ample bearing surface, and preventing grooves being worn in the tyres. Most sections of light rails err in this respect, with the consequence that they cut the tyres badly. The sleepers are of stamped steel weighing 40lbs. each. They have been spaced at distances so arranged that there is equal resilience both as regards rail joints and throughout the intermediate length of rail. This practice was first determined by theoretical considerations, the correctness of which was after-

* In the new regulations of the Government of India, issued since the construction of the Barsi Light Railway, for 2ft. 6in. and 2ft. gauge railways, the maximum axle-load on 30lb. rails has been fixed at 6 tons for locomotives, and 4 tons for goods and coaching stock. Mechanically, this is, of course, an absurdity, but the unnecessary limitation of axle-load on goods and coaching stock has probably been conceived with the object of discouraging the construction of railways of gauges narrower than the mètre, since it debars them of making full use of their natural traffic capacity.

wards demonstrated by a series of lever experiments, conducted on the permanent way by means of a lever testing machine, and finally by practice. At the Newlay Exhibition the smoothness of the track, laid on this principle, was generally remarked. The points and crossings are 325 feet radius, the angle of crossing being 1 in 8, and can be laid down either as right hand or left hand turn-outs. The intermediate rails are bent, cut to sizes and fitted, and are shipped complete with each set, so that, on arrival, they can be laid exactly as they are.

Before leaving the subject of permanent way, I wish to emphasize the necessity, in regard to light railway work, of abandoning the extremely high standard of construction considered necessary on standard gauge railways, and adopting a standard which, while it takes nothing away from the efficiency of the line as a means of transport, reduces the cost per mile to a very appreciable extent.

One of the advantages of the 2ft. 6in. gauge is that it requires no raised platforms. All that is necessary is a well drained gravelled space, edged with stone slabbing to mark its boundaries. Compare this with the cost of paved platforms raised two or three feet above rail level for a length of 600 to 800 feet, to which is added the cost of the extra height of the foundations of all station buildings placed upon such platforms. On the standard gauge, and with English types of carriage stock, such platforms are practically a necessity on account of the great height of carriage and wagon floors above rail level. For light railway work, I am against all ornamental and unnecessary expenditure, particularly as regards the erection of permanent buildings, for the accommodation of employés, on a scale of extravagance altogether above the kind of habitations in which they are accustomed to live, and also as regards lavish accommodation at stations before traffic requirements are thoroughly tested.

In my opinion the fact that it is essential to their financial success that narrow gauge light railways have to be built and worked on principles and guided by rules totally divergent from those in use on standard gauge railways is a very strong argument in favour of their independent administration. The whole bent and training of the rank and file of the staff of a standard gauge line is towards solidity and lavish expenditure, and with the advent of heavier train loads and higher speed this tendency will become more and more pronounced. The metier of the light railway man is, on the other hand, to eliminate expenses, superfluity, and complexity in every shape and form, and to evolve a type of line on which efficiency of action is combined in every department with the greatest simplicity of equipment. To place the working of a narrow gauge line, on which such a policy is required, in the hands of a staff furnished, changed and controlled by an adjoining standard gauge railway, and to expect it to carry out a rôle totally opposed to all its previous traditions is not likely to produce the desired results, and, so far as I am aware, has never yet done so.

As it is practically impossible to effect any useful reductions in the cost of standard gauge permanent way, I am satisfied that if any considerable development of the light railway system is to take place in England, it must be on the narrow gauge, so as to obtain the full maximum advantage as regards first cost. In this event it is of the very greatest importance that one standard gauge should be fixed for such narrow gauge lines, so that rolling stock may be interchangeable. It is inevitable that light railways, although beginning with isolated projects, will join up to one another. I go further than this and say that light railways in England will be as unsuccessful financially as those in Ireland, unless some central organization can be brought into being to undertake their management and working. The inordinate management charges following on the independent direction of undertakings of extremely short mileage, together with the abnormally heavy capital cost per mile of the Irish 3ft. gauge light railways, are responsible for the generally unsatisfactory character of returns on capital invested. Greatly improved results would follow were all these Irish light railways to be amalgamated into one large undertaking, so that the proportion of management charges to other expenses could be reduced, together with the cost of the maintenance and renewal of rolling stock. At present every line has its own little workshops, with its own patterns of rolling stock, several patterns existing sometimes on one line. When new engines or wagons are required they are bought one or two at a time on very disadvantageous terms of payment. All this should be swept away. Under one large company, or central management, the rolling stock should be standardized, so as to interchange on every line of the same gauge, and with larger quantities of engines, carriages, and wagons of standard types, they could be purchased and repaired with much greater economy than obtains at the present time. Were this to be done the financial standing of Irish light railways would assume a very different aspect. As it is, these small lines, working under the above named disadvantages, are nevertheless doing extremely good work in developing the resources of districts beyond the reach of ordinary railway communication, and, notwithstanding the baronial rates that are levied in most cases to supply the deficiency between profits and the guaranteed interest on capital, it is certain that they are popular.

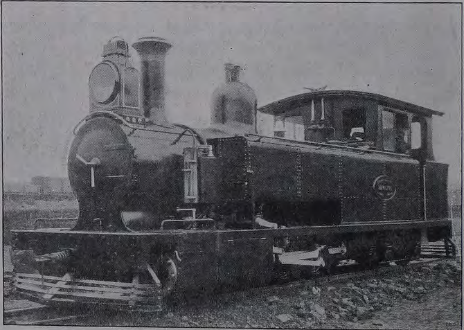
The Barsi Rolling Stock—Locomotives.

The principal novelty in the Barsi Rolling Stock has been the adoption of a uniform working axle-load throughout for engines, wagons, and carriages; the working axle-load being also the maximum adopted for the rail, namely five tons. On all other light railways, and indeed I may say on all railways with which I am acquainted, it is customary for the engine axle-loads to be much greater than those in use on the carriage and wagon stock.* On the 3ft. gauge light railway in Ireland, for instance, of which there are now eleven with a total length of 2,025 miles, the maxima axle-loads on carriage and wagon stock vary from three to four tons, while the engines have axle-loads of eight and nine tons, requiring rails of 50lbs. per yard, or exactly double what would have been necessary if the engine axle-loads had been maintained at a figure approximating to the maximum axle-load of the carriages and wagons. The additional weight on the wheels of these Irish engines was totally unnecessary, as has been proved by the Barsi engines, whose total adhesion and tractive force is greater, notwithstanding their much smaller axle-load. To get the greatest cubic and load capacity out of narrow gauge wagon stock, the maximum axle-load must be utilised to its full extent. We arrive therefore at a principle in light railway construction which is that the greatest economy, *i.e.*, the maximum carrying capacity on the minimum weight of rail can be secured only by uniformity of axle-load.

The next point to which I would direct attention is that the whole of the Barsi rolling stock has been constructed on a system of standard details, so that like articles are interchangeable throughout. Each part of the engine has been most carefully designed, not only with reference to its work but also with regard to its position and the effect of its weight in securing that the maximum axle-load should not be exceeded on any single pair of wheels. Every single detail has been allotted a standard number, which is stamped upon it, so that in the case of damage from accident or in the course of

* See footnote to page 294 ante, on axle-loads.

ordinary wear and tear, all damaged parts can be obtained from the headquarters stores depôt, or ordered direct from England merely by cabling their standard numbers. The same principle of the standardization of parts has been carried out throughout the carriage and wagon stock. This system is productive of extreme economy, not only in construction, on account of the lessened cost of the manufacture of numbers of identical articles, but also in maintenance, as it allows of the behaviour of parts being kept constantly under observation. In the working of rolling stock, designed on these principles, the quantity of any one standard part worn out or repaired each half-year arrives at a figure dependent on the number in use and the train-mileage run. If the number be found to be abnormally high, attention is directed to the subject, and the defect whether of design or material is rectified. It will be seen that when once the relationship of repairs and renewals to train-mileage is ascertained, the quantities of all standard duplicates, required for renewal in any half-year or on any given train-mileage, can be estimated for in advance with very great accuracy. In the case of light railways in India and the Colonies, a line has to draw on England



LOCOMOTIVE—"HAMILTON."

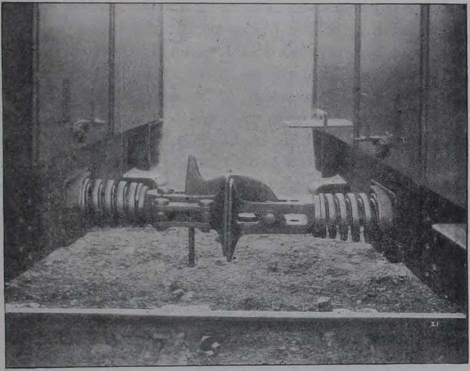
as its base of supplies. Consequently it is most important that the stores can be indented for sufficiently in advance to prevent rolling stock from being incapacitated and withdrawn from traffic because they have not arrived in time. The Barsi rolling stock has been specially designed with reference to its adaptability for military purposes, and I need hardly say how extremely important in military operations it is that repairs should be effected with the least possible delay. Duplicates of all parts particularly subject to wear should be sent out with the first shipment of material. The standard detail system permits of the system of repair by exchange. Exchange is a matter of minutes, while repair is a matter of days and weeks. We arrive now at another principle in light railway construction, namely, that the rolling stock should be of the fewest types, and that each of those types should be built up of the greatest number of standard parts.

The Barsi engine, a view of which is given, is 29ft. 6⅛ins. long over buffers, and weighs 29 tons 8 cwt. in working order and fully loaded. It is of the consolidation type, having 8 wheels coupled of 2ft. 6ins. diameter, and is provided with a four-wheeled swing link bogie truck at the trailing end. The cylinders are 13ins. diameter by 18ins. stroke. The working pressure is 150lbs. The slide valves are balanced and driven by Walschoert's gear, dispensing with eccentrics. The tanks have a capacity of 800 gallons and the coal bunker of four tons. The tractive force of the engine is 11,088lbs. with a cut off at 75 per cent. of the stroke, 10,650lbs. at 70 per cent., and 9,610lbs. at 60 per cent. The slidebars are boxed in to keep out dust, the engine being built for use on ordinary roads. All the wheels, including those of the bogie, are fitted with brake-blocks, operated by hand or steam at will. The engine is fitted with a whistle for train signalling, a syren to warn cattle off the road, and with a steam bell for use when moving through the streets. The total wheelbase is 18ft. 6ins., but the rigid wheelbase is only 8ft. 3ins., which enables the engine to run round extremely sharp curves. The engine and all other vehicles are fitted with the Jones-Calthrop Patent Flexible Buffer-Coupling. At the Newlay Exhibition this engine took a train load of 180 tons up a gradient of 1 in 57, occurring on reverse curves averaging 200ft. radius. The curves as laid down were parabolic, and at the sharpest point were equal to a radius of only 175ft. During the trials the weather was generally very bad and the rails greasy, so that the performance, which was repeated many times daily, was a severe test of the powers of the engine. On several occasions the train was stopped on the reverse curves when mounting the gradient, and was re-started without difficulty. The following views show a portion of the experimental train standing on the reverse curves :—

BARSI TRAIN ON CURVE.

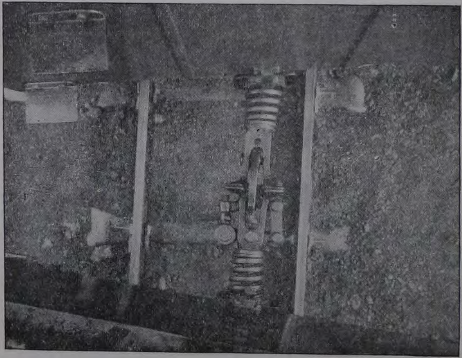
TRAIN ON S CURVE.

On a level straight line, this engine will draw 1,036 tons at 15 miles per hour. On the heaviest gradient and curve on the Barsi main line, namely 1 in 100 on 600ft. curve, the engine will haul 291 tons at 8 miles per hour. A train of 280 tons, composed of 13 low-side wagons and 1 brake, fully loaded, will have a tare weight of 65 tons 7 cwts., and will carry 210 tons of goods. As 16 trains a day can be run in each direction without difficulty, the theoretical capacity of a single line with crossing stations is no less than 3,360 tons each way, which is several times what is required at Barsi even in the height of the busy season.



JONES-CALTHROP PATENT FLEXIBLE BUFFER. SIDE VIEW.

The engine is fitted with a central buffer which also forms a coupling. This buffer coupling is a modified form of the Jones Patent Flexible Buffer, adopted as the standard for metre gauge lines by the Government of India, to which I have added rocking dishes which permit it to move laterally through an angle of 36 degrees. The two buffer heads are coupled by means of a central hook, and are drawn together by a right and left hand screw coupling, so that the buffer spindles become practically one solid bar. There is therefore no movement or slack whatever between the two heads. When a train is going ahead the two outer springs are in compression; in shunting the two inner springs are compressed. The buffer spindles are not at any time in rubbing contact with any part of the headstock, being supported only at the smaller ends of the springs, and, as there is also no rubbing of the heads, the wear and tear of the buffer is practically nil. It will be seen that this Jones-Calthrop buffer is what is technically termed a tight coupling, and, as there is no slack between the heads, it is impossible to cause damage by snatching, which is an important feature, since my experience of wagon repairs shows that 90 per cent. of the withdrawals of wagons from traffic are due to damages to draw-gear caused by snatching slack couplings when starting a train, or in taking up the slack at the bottom of inclines. The large angle through which the rocking dishes permit the buffer to move, has enabled me to put cars 40 feet long on this narrow gauge. The principal advantage of the buffer, however, is derived by the great freedom of the lateral movement, by means of which flange friction round sharp curves has been reduced to such an extent as to very appreciably increase the train load. The following illustration is a top view of a buffer between two 40 feet coaches standing on a curve of 175 feet radius, which shows the angles made by the ends of the coaches to each other and to the track, and also the angle of the buffer to the headstocks.



JONES-CALTHROP PATENT FLEXIBLE BUFFER. TOP VIEW.

I have no doubt that the large excess which our engine at Newlay drew over its theoretical load, calculated on the usual formulæ, was due in part to the reduction, as explained above, of resistances on sharp curves.

The Barsi Rolling Stock Wagons.

I now come to a description of the tare weights of the Barsi wagon stock, which have been designed to combine the greatest carrying capacity with the minimum tare weight, and which, together with the great power of the engines, formed the chief point of attraction at the Newlay Exhibition. It has been explained that in designing the permanent way and rolling stock for a narrow gauge light railway the principal object to be aimed at is to obtain the greatest proportionate traffic capacity from the cheapest possible track. With a given engine power, any reduction in the dead weight of the train produces a corresponding increase in its carrying capacity, and our object at Barsi with our large traffic has been to carry the heaviest goods load per train on the lightest tare weight compatible with a proper reserve of strength, and a due regard to the cost of maintenance and repairs. After careful examination of various systems claiming to effect reductions in the tare weights of rolling stock, I ultimately selected that known as Fox's Pressed Steel Underframes. By the adoption of pressed steel I have been able, while working to the uniform maximum axle-load of five tons, to design open wagons, 25 feet long over headstocks, with a paying load of 15 tons 18 cwt. and a tare weight of only 4 tons 2 cwt., the percentage of tare to the total being only 20·5 per cent. This low side wagon was placed under a test load of 40 tons of pig iron, with a temporary deflection of $\frac{5}{16}$ths of an inch between bogie centres, and without a trace of any permanent set. A second wagon was placed under the same load of pig iron at the Newlay Exhibition with the same deflection, where it remained for a week, and when unloaded there was again no trace of permanent set. The high side open wagons weigh 5 tons 7 cwt., and carry 14 tons 18 cwt. of goods. The covered wagons weigh 5 tons 18 cwt. and carry 14 tons 2 cwt. While I do not deny that other systems have their merits, I know of none other which can produce such results as these while maintaining simplicity of detail and the same reserve of strength.

Light tare weight effects a permanent economy in working expenses by making it possible to carry a greater quantity of goods per train at the same cost of coal, oil, and wage, and by reducing the wear and tear on permanent way. This is an actual saving of revenue, day by day and year by year, in respect of every train that is run. In regard to capital cost the results are of the highest possible importance. Had our wagon stock been built with the usual heavy tare weights it would have been necessary, in order to carry the same weight of goods in each train, to have adopted a greater axle-load, to have designed much heavier and more powerful engines, and to have employed rails and permanent way of much greater weight per yard.

To secure these advantages it would be worth while, if it were necessary, to pay more per vehicle for wagon stock. I want, however, to point out that although the cost of pressed steel, the "tubular" or any other system for effecting large reduction in tare weight, is undoubtedly greater per ton weight of the vehicle it is actually less per ton weight of the load. The design and carrying capacity of a vehicle is the proper basis on which to compare the relative cost of wagons. In purchasing wagons of a heavy tare you actually pay more for what you want to get rid of. I am, of course, comparing the cost of pressed steel with wagons of ordinary construction, which have been designed and built to give good results in working and maintenance, and not with some light railway stock with which I am acquainted, which is built only to sell.

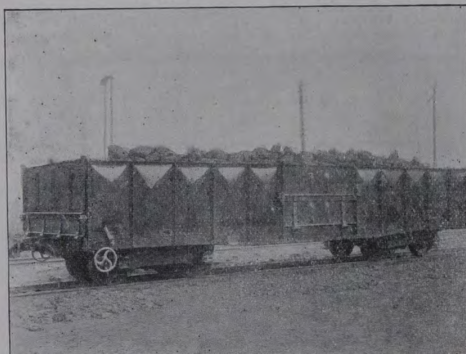
The wagon stock for all classes of work is of the bogie type, 25 feet long over headstocks, and 7 feet wide. The length over buffers of each vehicle is 28 feet 3 inches. The centres of the bogies are 16 feet 8 inches and their wheelbase 4 feet 3 inches. The weight complete on rails of each wagon fully loaded is 20 tons or 5 tons per axle. The bogies of both carriage and wagon stock are of the swinging bolster type and are identical and interchangeable. A few wagons have been fitted with bogies without the swinging bolster, for experimental purposes, but these bogies are interchangeable with the remainder.

The Timmis system of springs has been adopted throughout the carriage and wagon stock with much success in obtaining smooth running. The system consists in the use of duplex spiral springs, so arranged that when the vehicle is running empty, one spring only of each set is in action, but when running loaded both are called into play. This is a point of considerable importance for very light stock, since in the absence of this arrangement a wagon when unloaded would run virtually without springs, and so be subjected to unnecessary vibration, which means useless wear and tear.

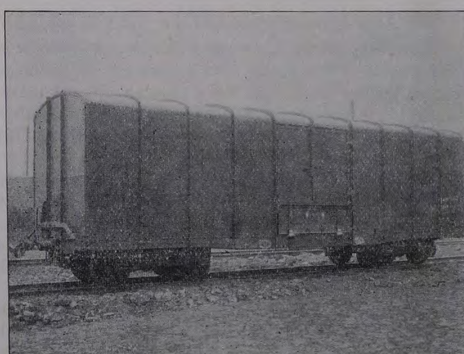
Low Side Wagon Loaded with Sacks.

The above illustration shows a low side wagon loaded with sacks containing sand. The first layer of sacks are placed with their ends lying upon the low side. This gives them an upward tilt which is communicated through each of the succeeding layers up to the top, so that bags and sacks loaded in this way cannot fall off. This wagon has sufficient capacity to carry full loads (15 tons 18 cwt.) of wheat, seeds, and pressed cotton, and is the best for general utility. The low side facilitates loading and unloading. It will be seen that the ends of this wagon are stamped from one plate. The brake acts on both wheels of one bogie and can be operated from either side of the wagon. This wagon weighs 4 tons 2 cwt. and carries 15 tons 18 cwt.

The next illustration shows a high side wagon loaded with coal. It is fitted both with side and end doors, the latter to enable guns and limbers to be carried. Owing to the end doors and their brackets, a wheel and chain is substituted for the end brake lever. This gear can also be operated from either side. The sides of these wagons are stamped and dished in sections. The dishing should be sufficient to deflect a bullet, while the flanges prevent splashing. This wagon weighs 5 tons 7 cwt. and carries 14 tons 13 cwt.



High Side Wagon Loaded with Coal.



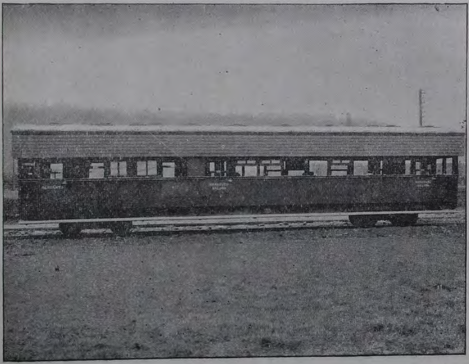
Covered Wagon.

The covered wagon, built entirely of steel, weighs 5 tons 18 cwt. and carries a load of 14 tons 2 cwt. Its capacity is 1,000 cubic feet. The body is 7 feet wide and 6 feet 6 inches high inside, and is designed to carry six horses with forage and attendants, and at a pinch it can carry nine.

The Barsi Rolling Stock.—Carriages.

The carriage stock for all classes of work is also of one length, namely, 40 feet 6 inches over bodies, and 40 feet over headstocks. The bodies are 7 feet 6 inches wide over sunshades and 6 feet 2 inches between standing pillars. The underframes for every class of vehicle are identical in every respect and interchangeable. The bogies are 28 feet centres, with a wheelbase of 4 feet 3 inches and, as stated, are interchangeable with those under the wagons. The cars for ordinary use are built to weigh, with a double complement of passengers and baggage, rather less than 20 tons on rail, which is equal to 5 tons per axle. They are capable of taking curves of 150 feet radius. The cars are supplied with gas fittings throughout. There are only two classes, namely, upper and lower class, but the lower class compartments are of a style and finish equal to that usual in the second class. We believe in catering for the comfort of our lower, or third class passengers, from whom we shall derive a large revenue.

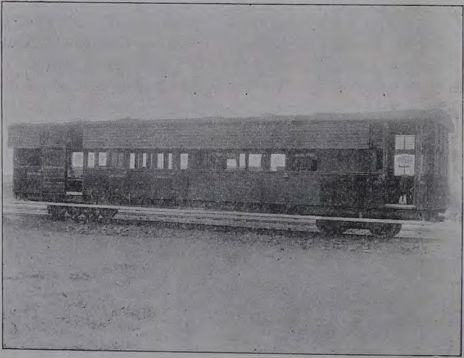
A passenger train made up of one upper class car, eleven lower



Special Saloon Car.

class cars, and one compound brake van, allows full seat room for 30 upper class, and 736 lower class passengers. In times of pilgrimages, or on other special occasions, one thousand passengers could be carried in a single train.

The Special Saloon Car contains a main saloon, a smoking or inspection compartment at the end, an entrance and luggage vestibule, a lavatory with a bath and wash basin supplied with hot and cold water, a kitchen and servants' compartment. The latter communicate with the entrance vestibule by means of a side corridor. The Car has sleeping accommodation for six passengers. These and all other cars have sunshades and double roofs, gas lights, louvre shutters, and venetian ventilators. This Car weighs 12 tons 13 cwt. all complete.



BRAKE VAN.

The Compound Brake Vans have been built with upper and lower class compartments to enable passengers to be carried by every goods train. The upper class compartment has seats for six passengers and sleeping berths for four, and is furnished with lavatory accommodation. The lower class compartments are fitted with cross seats and carry 32 passengers. The Brake Vans weigh 12 tons 1 cwt. each. In the lower class compartments the cross seats carry four passengers each comfortably, and at a pinch five.

The lower class cars have lower class compartments only, and carry 64 passengers. They weigh 11 tons 13 cwt.

Means for Avoiding Transhipment at Junctions Between Broad and Narrow Gauge Railways.

The value of narrow gauge in reducing cost is so great that any practical proposal, which promises to avoid the cost, loss of time, and damages to goods caused by transhipment, and yet permit the use of narrow gauge for short branch lines, will, in view of the light railway projects now being matured in England, at all events be regarded with interest. I propose to effect this by means of Transportation Cars, and Transfer Bogies; the former being intended for general use in England, the latter to meet special conditions in India and abroad.

The Transfer Bogies are placed under standard gauge wagons after their own wheels have been removed. The bolster of the narrow gauge bogie is furnished at each end with a dummy axle-box, sliding in the axle-guard of the standard gauge wagon, which is therefore carried on its own springs. The Transfer Bogies, however, are not suitable for light railways in England where the average length of line is so short, but have been devised for a special purpose, namely, with the object of carrying standard gauge wagons loaded with coal, which suffers much in transhipment, over long lengths of metre gauge line amounting in the case of the Southern Mahratta Railway to hundreds of miles. These coal wagons would come back to the junction and to their own wheels and axle-boxes, and the short time occupied in the exchange, effected by means of an hydraulic lifting plant, would be justifiable and economical.

An experimental four-wheeled Transportation Car, tested at the Newlay Exhibition, was constructed to demonstrate the feasibility of carrying by this means loaded lurrys from Liverpool to Manchester on a narrow gauge line, so as to avoid all transhipment between ships' side at the Liverpool Docks, and the warehouse in Manchester and *vice versâ*. This project is now under the consideration of a special committee of the Liverpool Chamber of Commerce, appointed to investigate means for transporting traffic in competition with unduly heavy rail charges. The result was a successful demonstration of the stability of the cars, and of the feasibility of the project as far as these mechanical proposals were concerned.

THE BARSI ROLLING STOCK AS APPLICABLE TO MILITARY OPERATIONS.

The theoretical requirements of a field railway, which I state with the diffidence which becomes a mere civilian, appear to me to be that generally the equipment must include permanent way, portable bridges, rolling stock, and all stores of whatever kind that may be required in any part of the world for use on an unsurveyed route through a country unprovided with railways, and so as to be entirely independent of local resources, and, in particular, as follows :—

1. The permanent way to be portable and of a pattern which takes the fewest men to handle and the shortest time to put together, and to be of the least weight and bulk compatible with the largest traffic capacity.

2. The rolling stock to have a uniform maximum axle-load, and to have the greatest load capacity with the lightest tare weight, compatible with a proper reserve of strength.

3. The wagon stock while adapted to the greatest number of purposes and contingencies to be of the fewest types. Details, as far as possible, to be common to and interchangeable in all types, and so that repairs in the field can be effected by the exchange of standard parts.

4. The rolling stock to be of such patterns that their erection on arrival should be an expeditious operation requiring neither tools nor workshops.

I wish to point out briefly to what extent the Barsi rolling stock fulfils these conditions.

As regards No. 1, both rails and sleepers stow perfectly for shipment. A 24ft. length of permanent way including ten steel sleepers can be put together *in situ*, keyed and fished by six men in about five minutes, when working systematically. The permanent way can also be carried in the wagons, put together with sleepers complete in 24ft. lengths ready for laying down. The weight of permanent way, with 30lb. rails and 40lb. sleepers, with the usual additions for contingencies and waste is 90 tons 16 cwt. per mile. The net load of stores which can be taken on a gradient of 1 in 100 is 210 tons, so that with 13 low side wagons and one brake a single train can carry two miles of track per trip, with a full complement of workmen. The Barsi rolling stock can transport in either direction a maximum of 3,360 tons daily over a section 20 miles long, with a ruling gradient of 1 in 100, and a maximum of

1,680 tons with gradients of 1 in 50 on curves of 250ft. radius. This is on a basis of 16 trains a day in either direction, which, with crossings, can be worked without difficulty. As regards troops, a battalion with stores and impedimenta could be carried in one train over grades of 1 in 100, and a half battalion over grades of 1 in 50.

As regards No. 2, that the rolling stock shall have a uniform maximum axle-load, and the greatest load capacity with the lightest tare weight compatible with a proper reserve of strength, the Barsi rolling stock represents, I believe, an advance on anything which has been done hitherto in these directions as regards light railways. The wagons are so light that they reduce the weight and bulk of permanent way to the smallest proportions, thereby increasing the length of track which can be carried in one ship, or by one train, and the permanent way being lighter, it is more easily handled, and laid quicker.

As regards No. 3, the Barsi wagon stock has been restricted to three tyres, which are all that are necessary for ordinary traffic purposes. The parts which are subject to wear and tear are identical and interchangeable throughout.

With reference to No. 4, that the rolling stock should be of such patterns that their erection on arrival should be an expeditious operation requiring neither tools nor workshops, the whole of the rolling stock has been erected in India under these conditions. The pressed steel underframes require no trusses, and very little packing, consequently they stow closely on board ship, and the risk of break-down from lost truss-bolts and nuts is avoided. Their lightness enables them to be shipped in large pieces, and to be handled with very elementary lifting appliances, so that the time lost on arrival, in erecting stock shipped in small sections for the greater convenience of handling, is avoided.

As regards landing carriage and wagon stock from vessels, the underframes can be lowered forthwith on to the bogies, which can be shipped complete with wheels, direct from the ship's side, and the cases containing sides and ends can then be lowered on to these underframes as they stand. The underframes as soon as they are on their bogies already form a movable wagon, and can be rolled away to sidings where their erection will be completed. One engine could be carried erected complete on deck, and slung down on to rails or run down an inclined plane, so as to be ready for the first lot of wagons when put together. It is of the greatest importance to keep the landing clear of accumulations of stores.

The Barsi carriage stock has been specially designed to allow of speedy erection after shipment. The floors, sides, ends, roofs, and partitions are shipped in single pieces. The partitions are packed in a square case by themselves, and the two sides complete, with doors and sunshades, in one long case by themselves. With extemporized lifting appliances only these cars were put together in running order on rails within three days from the time of unpacking the cases. Military carriage stock would be of the same length but of a simpler character, and could be put together in a few hours.

The object of this system is to leave the parts as complete as possible so that the work of erection on arrival is made as simple and expeditious as possible. For expeditious work I do not believe in the system of designing rolling stock for military purposes out of permanent way material, with small units which can be converted into larger units and so on. The whole thing becomes a large Chinese puzzle, and unless you have men who are thoroughly acquainted with all the parts and their many combinations the result is too often a big muddle. What is wanted is the fewest number of parts, and extreme simplicity throughout so that it is perfectly obvious to an ordinary mechanic where everything has to go without requiring either drawings or instructions.

To be of the fullest use a military railway must keep abreast of the advance of the troops, which means progress at an average rate of ten miles a day. I regard this as a practicable aim provided the work of construction proceeds with a maximum speed and efficiency from the first day and hour of debarkation. Twenty miles lost, by avoidable delay at the start, may never be made up. It is only continued practice that can ensure the smart start off. No railway corps can make a proper show on service unless all the operations of disembarkment, erection, alignment and construction are as familiar as are the ordinary evolutions on the parade ground. Once this familiarity is attained under conditions approximating to those existing on active service I see no reason why a light railway could not be laid down at a speed much greater than that which has as yet been attained in the field.

ADDENDUM.

THE Barsi 2 ft. 6 in. gauge Light Railway was opened for traffic in March last, and the above paper was read about a month previously. Sufficient time has therefore hardly yet elapsed to afford a thoroughly conclusive test of the value of the principles upon which both permanent way and rolling stock have been designed; but the experience of the working of the railway during a period of an almost unexampled combination of troubles, including plague, cholera, and famine, and their ruinous effects upon traffic has been sufficient to indicate that the importance claimed for them, from the commercial point of view, has not been overrated.

It is a satisfaction to be able to state, notwithstanding these troubles, that the working expenses in India were no greater than 49·99 per cent. of the gross receipts, and that the net profits earned were about 4 per cent. on the capital of the Company. Under normal conditions of traffic, and more particularly when the extensions of the line are completed, I have no doubt that the percentage of working expenses will be reduced. The Company have the good fortune to possess in Mr. A. L. Alexander, M.I.C.E., a resident engineer and agent distinguished alike for his capacity, tact, and energy. His most efficient management claims grateful acknowledgment and must be taken into consideration with any suggestion that the power of the engines and the light tare weight of this rolling stock have been the chief factor in keeping down working expenses to the above-mentioned low figure.

As regards the bulk capacity of the Barsi rolling stock in practice, the resident engineer and agent reports in a letter just received that he has carried the whole of the machinery and buildings of a ginning factory in one special train. Amongst the machinery was a boiler 28 ft. 6 in. long and 7 ft. 6 in. in diameter and weighing 14 tons, carried on one wagon, and a fly wheel 10 ft. in diameter and weighing 4 tons carried in another. He concludes by saying:— "It is worthy of note, that this is the first time in India that such a weighty piece of machinery as the boiler has been carried on a

2 ft. 6 in. gauge railway; also that (I believe) ours is the only railway in India, broad or narrow gauge, where one piece of machinery of the dimensions previously quoted has been carried on an ordinary goods truck." On the arrival of the boiler at the junction with the Great Indian Peninsula Railway, which is of a gauge of 5 ft. 6 in., it had to be placed on two broad gauge wagons specially sent up from Bombay to receive it.

With reference to the bulk and weight capacity of the wagons for ordinary traffic, such as wheat, linseed, salt, cotton, piece goods, etc., the following table gives the results at present attained, which, as regards open wagons, are being gradually improved by better stowage :—

CAPACITY OF BARSI WAGON STOCK IN PRACTICE.

Type of Wagon.	Tare Weight.	Maximum Load.	General Traffic Average.	Linseed in Bags.		Fully pressed Cotton Bales.	
	T. C.	T. C.	T. C.	No. of Bags.	T. C.	No. of Bales.	T. C.
Covered ...	5 18	14 2	14 2	156	14 0	78	14 2
High-side ...	5 7	14 13	14 10	157	14 2	74	13 15
Low-side ...	4 2	15 18	14 18	160	14 7	74	13 15

The Secretary of State for India has accorded sanction for the extension of the railway to Pandharpur, a further distance of 31 miles, and included in the rolling stock required will be two transportation cars for carrying 5 ft. 6 in. gauge wagons without transferring their contents. These have also been designed particularly with reference to military requirements, for carrying guns, howitzers, and commissariat vehicles. As the wheels of the carried vehicles will be only nine inches above rail level, they will be capable, on occasion, of very rapid entrainment and detrainment.

Transportation cars of a somewhat similar character will be employed on the Welshpool-Llanfair 2 ft. 6 in. gauge Light Railway, recently sanctioned by the Light Railway Commissioners. In this case they will be used for the transportation of fully loaded 4 ft. $8\frac{1}{2}$ in. gauge railway wagons over the narrow gauge line. The advantages of avoiding transhipment in England are considerably greater than in India, where the low cost of labour makes it generally preferable to tranship goods rather than incur the haulage of additional dead weight.

Ten wagons of the Barsi low-side type have been ordered by the War Office for experimental purposes, and will shortly be completed. Following on the results already achieved by the Barsi Light Railway, the *Times of India* and other Indian newspapers are now strongly advocating the immediate construction of light railways of the Barsi type as a means of holding and pacifying the North-West Frontier.

With reference to the system of standard details, by which all the parts of rolling stock are coded and numbered, a case occurred, shortly after the opening of the line, of a derailment of a locomotive, through a station-master omitting to lock the points; and as it was travelling at some speed with a heavy train behind it considerable damage was done to the engine. The numbers of the damaged parts were at once cabled home, and the order for their renewal was in the hands of the makers within three days, and, but for the engineers' strike, the renewed parts would have been on their way to India within two or three weeks of the accident.

E. R. CALTHROP.