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PREFACE.

THE Volume now published for 1885, which should have been issued to subscribers in 1886, but could not be got ready in time, contains much useful information with respect to both civil and military engineering.

The lectures on Road Making in Western India, by Captain W. W. Robinson, give an account of work actually done, and form a link between the instruction given at Chatham and the practical work which has to be carried on in whatever part of the world the Engineer may be located.

The lectures on Frontier Railways in India are not only of engineering but also of historical interest, and form a capital sequel to the lectures on Road Making; the account of the difficulties experienced in the work, and how they were overcome, will be a valuable guide to those who have to undertake similar operations in the future. The illustrations we re-produce will, it is hoped, give some idea of the country through which the line runs.

Lieutenant Nathan's paper on the Sûdan Military Railway might, in sequence, well follow on after the Indian Frontier Railways, for where the one treats on the difficulties of construction, the other deals more with the difficulties of working the railway.

Captain Tizard, R.N., contributes a lecture on Marine Surveying, which we are glad to welcome to our pages. The Admiralty charts are so much used in the various duties of the Corps, that it is interesting to have an account of their preparation, especially as the Royal Navy and the Corps in this and other branches of their work come so closely together, in surveying particularly, for here they are only separated by the *low water line*.

The Application of Infantry Fire in the Field, by Captain C. B. Mayne, will, we anticipate, be well received, as it deals with the same subject as his book on *Infantry Fire Tactics* which attracted so much attention a year ago.

Captain G. S. Clarke contributes an account of the Lydd Experiments in 1885, which brings the subject up to date. The notice does not give as much detail as we have supplied in former years, but deals with what is more useful, viz., deducing the lessons which are to be gathered from each series of experiments. Captain G. S. Clarke also contributes a paper on Invisibility, which is particularly interesting, and gives hints which will be of the greatest value to those who have to design, or rather locate, coast batteries.

Semi-Permanent Infantry Redoubts, by Major G. R. Walker, R.E., gives a general outline of the new departure in the construction of detached forts which has caused so much discussion lately.

We must not conclude this notice without calling attention to the views of the Poor House at Halifax, N.S., and of portions of the Harnai Railway, which are reproduced from photographs by Sergt.-Major Husband's (R.E.) papyrotint process. These must not, however, be considered good specimens of his work, as in the first place the negatives for the reproduction had to be taken from silver prints, and secondly, as the original photographs were taken with a view to illustrating reports, and not as specimens of the photographic art, they were, therefore, very unfavourable subjects to reproduce.

FRANCIS J. DAY, Capt., R.E.,

Secretary, R.E. Institute, and Editor.

January, 1887.

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PAPER I.

ROAD MAKING IN WESTERN INDIA.

BY CAPTAIN W. W. ROBINSON, R.E.

Two Lectures delivered at the S.M.E., in March, 1885.

LECTURE I.

GENTLEMEN:—I propose to give you some account of the road works I was engaged on, or saw while serving, in the Bombay Presidency. Different kinds of country have different kinds of roads particularly suited to them, so I will begin by saying that what I shall describe belong, more especially, to that large area of India covered by the trap formation of the Deccan (see *Plate* I.), a tract of about 200,000 square miles, that is, about the size of France; a tract interesting—*geologically*, as being one of the largest volcanic overflows in the world; *ethnologically*, as being the country of the Mahrattas, and curiously enough the limits of their language are, except in the north, nearly co-terminous with the trap formation; *historically*, as having been the scene of Sir Arthur Wellesley's campaigns, of the victories of Koregaum and Assaye, and later on of Kirkee. It is a table land some 2,000 feet high; its western edge buttressed up by what we English call the Western Ghâts. Its top is an undulating plain crossed by ridges of rocky hills, chiefly running east and west as spurs from these mountains. The rainfall varies from over 200 inches on the range to less than 20 inches over the eastern districts of the table land.

Though it is to this area that the system described is more peculiarly adapted, it was also used in the Bombay districts further south, where the country belongs geologically to the Madras Gneiss formation, to which it was almost equally suitable.

Prospecting.

I will begin with the prospecting for a new line of road in this area, and as all the text-books on road making begin by saying that a perfectly straight road is what you should aim at on a level plain, I will mention that the only one I had to do with, some five miles long, was dreadfully expensive compared with what a little deviation would have made it, and was only made for special reasons; while similarly, a brother officer and myself having laid out seven miles perfectly straight for a railway across a perfectly level plain, and for a railway that seemed very attractive, it was subsequently found that the line, by sweeping round the edge of the plain in easy curves, avoided all the cultivated land we had cut through, and would therefore be much cheaper, and much better for being on harder ground, and well away from a river which had troubled us.

As to deviating from the direct line if there are difficulties in the way, I always think it worth while remembering that the circumference of a semi-circle, which is an extreme deviation for a road to connect two places at the ends of a diameter, is after all only about half as long again as the diameter, the straight line between them; and if there were hills across that diameter which the circumference would avoid, this difference would be much reduced by the extra length due to the curves and windings in crossing them at a gradient, besides saving for ever the labour due to going vertically up and down.

Another point to be attended to in prospecting your line is to prospect it throughout, and survey it from end to end before beginning to make your road. In going up the Bolan Pass to Afghanistan, in 1879 and 1880, at a certain point the military road forked, and a person who had not received a friendly warning, would be likely to take the better looking branch, and following it for some miles find, after having mounted by it high into the hills, that it stopped short among some impossible cliffs, and to have to retrace his steps, not too well pleased with the "sell," and his poor pack animals none the better for the extra miles. This road, with elaborate dry stone retaining walls, and much rock cutting, had taken the labour of two companies of Bombay sappers, and numerous infantry working parties, for months diverting their efforts from the improvement of the regular track up the pass. And all to no purpose, because the proposed road was never surveyed through, but was surveyed bit by bit as the work progressed, until it got into insurmountable difficulties. I should, in justice to the corps, mention that it was carried out against the written protest of the senior R.E. officer present. I might quote as instances of the same fault other military roads in Afghanistan, where long lengths of easy road had had to be connected by short lengths of very difficult work.

Native Tracks.

Again, in prospecting for a road it did not do to be too much guided by old native tracks running in the same direction. It had to be remembered that these were often thrown into an entirely new line of country by some obstacle, which, although a serious or impossible one to travellers finding their way along as best they could, was not so to the Engineer. For instance (see *Fig.* 1, *Plate* II.), I know a road which seemed to have been evidently guided by the old track, which the map showed to have followed somewhat the same course. The latter had been forced to quit the bank of the river it had before been following by a steep spur (*aa*), with a precipitous face abutting on the river, and had crossed the hills instead. The road had been made to do the same, but being limited by considerations of gradient, which the old track was not, it was much longer. It ascended some 300 feet by a gradient of about 1 in 20, then meandered about on the hill top, and finally descended to the river bank on the far side. But if the designer had only examined the ground, and cast himself loose from the old track, he would have found that by a single deep but short cutting through the spur, he could have kept along the valley, and thus have not only shortened his road, but saved traffic for all time from ascending some 200 feet, only to descend again, while the cost of the deep cutting would not have been nearly so much as of the miles of hill-side road he was involved in.

Selecting line of Road in easy country.

We were greatly assisted in prospecting for roads by the Indian Government maps, known as "Indian Atlas Sheets," scale 4 miles to 1 inch. Even on this small scale the hill shading and water-courses indicated pretty well to any one accustomed to surveying, and who knew the trap formation, where passes through hills might be found. After examining and selecting these, and also the rivers for favourable sites for bridges, though there was more choice about the latter, a line was finally selected in which there were a certain number of ruling points, such as passes through the ranges of hills, favourable crossings of rivers, or villages to be connected, the final survey then consisting in joining these as directly as possible without exceeding certain given gradients. In Bombay engineering the limiting gradient for crossing mountains has usually been 1 in 20, and for undulating country, though practice has varied, the best roads do not exceed 1 in 25, or even 1 in 30. It is much better to aim at easy gradients, such as these latter, than to have lengths of nearly level road with shorter sharper inclines.

In the country I have described it was much more economical and easier to make a good road by keeping off the deep "black-soil" of the low ground and skirting the high ground and hills, by which means, besides getting a better foundation, the water courses were crossed near their heads by numerous small culverts and drains built on good foundations, instead of where these smaller streams had united to form a river which would require a bridge often with troublesome foundations and embanked approaches. The gaining of these advantages justified a good deal of deviation.

In marking out the line over level or undulating country, it was necessary to be guided by a common sense adjustment between the desire to get to the next fixed point as directly as possible, and the wish to avoid obstacles and gradients.

Selecting line over hills.

Where, however, one of the fixed points was a pass through a range of hills, the line was decided by the gradient, which had to be worked downwards from the pass or point on the water-shed on each side of the range. I need hardly say that where the hills involve your using steep gradients it is inadmissable to work up-hill, for the steeper slopes of mountains being always near their summits there is far less choice of line there than lower down; and starting your gradient trace at the foot-slopes, you cannot guarantee its carrying you to any given pass in the summit of the range, unless indeed you use zig-zags, which we were stringently forbidden to do. Indeed, to use them can hardly be called engineering. They are most dangerous in case of runaways, and Indian bullock-carts are very apt to become runaways down-hill, as the bullocks have no means of holding back the weight except with their horns against the yoke as it is pushed forward. Zig-zags cause a frightful block when strings of ascending and descending carts meet at an angle, and indeed are bad enough with a string of carts travelling in the same direction.

Even on a military road they should not be used, for the road having to be executed quickly and roughly is all the more reason it should be lined out skilfully, and not for laying it out badly. Military considerations may in rare instances necessitate zig-zags; for instance, your line might otherwise run too far out of sight of some protecting fort or post, or make it less easy to protect. Probably this was the reason of the zig-zag descent of the Khojak Pass, between Quetta and Kandahar. But the broken carts lying in the ravines beyond each angle proved their danger, and the heavy labour on all the men that could be mustered to hold on to each cart, and prevent its meeting the same fate, brought unpleasantly home their disadvantages to the transport officer. On two other military roads in South Afghanistan I saw them used without any excuse whatever. Another fault in a mountain road is to have in a descending gradient any portion of the road rising again with an upward slope, thus giving unnecessary labour to traffic. Several level portions at intervals are, however, good as rests to tired draught animals.

Mountain Roads.

Next to explain the laying out of one of our Bombay mountain roads—I apologize to Bengal Engineers for calling them "mountain" roads, as they are nothing to the engineering gymnastics of the Himalayan roads so named. I propose to describe in detail the most important road of the sort I had to do with, and on which I spent two of the pleasantest years of my tour of service in India.

The Western Ghâts rise like a wall from the low country along the west coast of India, and form a ragged buttressed edge to the Deccan table land, above which, however, their peaks lower considerably; some to a total height of 5,000 feet above sea level. From these peaks as nuclei stretch out spur ranges across the table land, gradually dying down into the plain eastward. Following the principal valleys between these spur ranges, the native tracks have selected those which lead to the lowest notches in the western range, and there descend by sharp zig-zags to the low country. And it is these descents, or "ghâts," which have given its title to the range itself.

The Amba Ghât road was to connect a town on the table land, about 40 miles east of the water-shed, with a small port on the coast, about 30 miles from the foot of the escarpment. The difficult part of this line was the descent from the level of the table land to that of the coast down the escarpment of the Western Ghâts. In starting to lay out this descent, or "ghât," (*vide Plates* II., III. and IV.), its designer, Major W. M. Ducat, R.E., the executive engineer, whose assistant I had the honour to be, was tied by two rules, namely, (1) that the gradient should not exceed 1 in 20, and (2), that no curve was to be of less radius than 60 feet, though, actually, so sharp a curve was only used in one or two instances. First, in prospecting for the line, we had to examine one of the above mentioned native tracks, or bullock roads, connecting the two places. It was found by barometer that of several notches or passes in the range lying in the right direction, this bullock track had followed the valley leading up to the lowest, although, owing to its constructors not being able to attempt any very heavy work, they had not taken advantage of the notch, but had had to cross the water-shed to one side of it, and some hundred feet or so higher, in order to get what I may call a projecting buttress to the escarped western face favourable to cutting the short sharp zig-zags by which their road descended (see *Plates* III. and IV.). This pass (marked X, *Plate* III.), named after the adjacent village of Amba, having been selected, it was evident that standing on its saddle and facing outwards, the road might either turn to the right or to the left, and thence down the mountain side in one of these directions.

But at about a mile towards the right or north, there joined the main escarpment, by a depressed saddle (S, *Plate* III.), a very prominent spur-range stretching out across the low country. By barometer it was ascertained that this junction saddle was some 450 feet below the level of the pass. Now it was evident that if the road could only be carried down from the pass, so as to reach the junction saddle without exceeding the limiting gradient of 1 in 20, it could be turned off on to the spur-range, and would so not only be proceeding more directly towards its destination on the coast lying nearly due west, but the spur-range was found to be not nearly so rocky or to have the same step-like precipices as the main range, so that once on it the road would be much more easily made. No such advantageous spur presented itself to the south; it was evident (and a clinometer trace actually carried down by a previous prospector proved this), that a road at the given gradient in that direction would for miles have to be notched into the face of the main escarpment, and meet with several more lines of rocky steps. A rough triangulation on the hill tops having now been made, the relative positions of the pass and spur-range with its connecting saddle were fixed, so that the horizontal distance between these two ruling points, namely, the pass at the water-shed and the connecting saddle, was pretty accurately ascertained. The difference in level was, as I have said already, found by barometer. Now as a gradient of 1 in 20 descends 264 feet per mile, it was evident that it would take nearly $1\frac{3}{4}$ miles for the road to descend 450 feet, and as the junction saddle was only a mile distant, it would pass much above it. But added to this, it would, owing to the configuration of the range, pass round a corner of the mountains where the escarpment broke back, and have got into great difficulties. On examining the pass (X) in the crest of the range, it was evident from its cross-section (*Plate* IV.) that its notch could be deepened a great deal by means of a cutting, so that the road through it would emerge on the escarpment face at a much lower level, or the same thing might be arrived at by means of a tunnel. Again, the spur range joined the main escarpment by a saddle, shown in profile on *Plate* IV., which it was found could be raised by means of an embankment (see *Figs.* 1 and 2, *Plate* II.). Then assuming different depths of cutting at the top pass, several gradient traces were run from it along the face of the main escarpment by means of a clinometer, and these showed that starting with the deepest practicable cutting at the pass, namely 85 feet, (any deeper would have made the road emerge in the face of a vertical rock face), there was just a hope that the line when carefully laid out at the full gradient would be able to cross on to the spur-range on a practicable embankment. A more careful gradient line, laid out with a level, the pegs being put in every 50 feet or 100 feet, confirmed this hope.

The ordinary procedure for laying out the road would have been to trace this gradient line at something easier than 1 in 20, say at 1 in 22, or even 1 in 24, to be judged of by experience of the style of ground, so as to allow of the probable shortening of the line when laid out into true curves and straights, or when adjusted for cross section. For instance, in *Fig.* 1, *Plate* V., if *cdef* be the pegs of a line laid out on the ground at a given gradient, say of 1 in 20, and the road be made on the curve C D E F, so as to throw it more into cutting and to make a true curve of it, then the actual gradient of the road would be steeper than 1 in 20, as it falls the same vertical height between *c* and *f* in a shorter distance than the gradient trace. And to prevent the road from being steeper than 1 in 20, the surveyor would have had to use his judgment in laying out his line *c d e f* at some easier gradient to allow of such shortening; and this allowance he would probably make at once for his whole length of 1 in 20, by laying out the gradient trace at something easier.

Again, cross sections would have been taken at each of the pegs (*a b c*, &c. *Fig.* 1, *Plate* V.), and the trace having been traversed by compass or theodolite, it would have been plotted on paper. Then the cross sections would have shown whether the centre of the road could be made to coincide with the peg of the gradient trace, as in *Fig.* 5, *Plate* V., or would have to be thrown in towards the hill-side so as to get the road wholly in cutting, as at the steep cross section in *Fig.* 3, or whether, as in *Fig.* 4, it was indifferent so far as the cross-section was concerned, and the road might even be thrown outwards with its centre at G instead of at *g*, so as to be entirely in embankment.

Measuring off these settings in or out on the sections, as *c c'*, *Fig.* 3, and plotting them on the plan of the gradient trace, *Fig.* 1, we get the line *a'b'c'd'*. Then the line of true curves and straights, A B C…K, most nearly coinciding with these points, would be drawn by means of a set of curves, or of circles of various radii cut out of card or stiff paper, of which the one whose edge most nearly coincides with the adjusted points *a'b'c'* is selected and used for tracing the curve. Then always supposing that the allowance made in the gradient trace has been sufficient to allow of this adjustment to true curves, without making the road exceed the given gradient, the final centre line A B C, thus arrived at, would be marked out on the ground from the original pickets as follows, the positions of the straights between curves being set out by off-sets from the pegs of the gradient trace. For instance, in *Fig.* 1., *Plate* V., the straights A C and at K would be laid out by off-sets from *a*, *c*, *k*, *h*. These straights being thus determined, if possible their intersection is found and marked on the ground, as at *a*, *Plate* IV. (see red letters), and the angle at the intersection being measured by theodolite, the formula to be found in Molesworth's *Pocket Book*, or the *R.E. Aide Memoire*, under "Railway Curves," gives the distances which must be measured from the intersection in the direction of the straights to fix the tangent points of the proposed curve with those straights.

But on a steep rocky hill-side, as at the upper part of Amba Ghât, it was often impossible to fix the intersection of the two straights produced, as for a salient curve it would fall so far down the slope, as at *c* (see red letters), *Plate* IV., as to be inaccessible or impossible to measure from, while for a re-entering curve it would be too far up the ravine and inconveniently high. In such cases a method of fixing the tangent points by measuring two angles, as at *c'* and *c''*, *Plate* IV., is given by Molesworth's *Pocket Book* and other books of reference.

From one or both of the tangent points so fixed, the curve would be laid out in chords, say of 20 feet for the small curves of a road like the Amba Ghât, by one of the methods you have learned on the field works course, and the formula for which are given by Molesworth, the *R.E. Aide Memoire*, Rankine, and other books; preferably, as was done at Amba, by means of a theodolite, using tangential angles.

After a little practice and experience of the ground, in all but specially difficult cases, the plotting on paper might be dispensed with, and the same adjustments of setting in or out to suit the cross section, and of laying out into true curves and straights, might be done at once on the ground, always remembering that the whole art consists in fixing the directions of the straights, after which one or two calculations of the tangent lengths, and of the distance of curve from intersection, would show what radius of curve suited the ground best.

In many cases the actual straights between curves were only a few feet in length, still their prolongations were the ruling lines of the trace. I would exhort you never to make one curve join another without some straight between, for in executing the road work it might be found convenient to alter a curve, for which a length of straight on each side allows some margin; without which the adjacent curves would have to be altered and re-lined out also, and give a great deal of unnecessary trouble.

In our case, at the Amba Ghât, it was such a near thing our reaching the junction saddle S at all, that no margin for shortening could be allowed by laying out the gradient trace at an easier slope, and then putting the straights and curves for the whole length at once as above. We knew that if anything we had to lengthen our gradient trace, always remembering that for every extra 20 feet of length gained we got 1 foot vertically lower, and would reduce by so much the embankment we should require to cross the saddle at S (*Plate* III.). Now suppose ABCD......on *Plate* IV. are curves where the road passes round the spurs A, C, F, and the ravines B, E, G, then it is evident that if we follow the continuous red line, we shall make it longer than the dotted red line, but that on the spurs the road will be thrown more out into embankment, and in the ravines more into cutting. And this is what we had to do in order to gain length; we had to keep our curves as far out on the spurs and as far in at the ravines as we could. For this the difficult points were at the straights between, which necessarily occur just at the steepest cross slopes. In many cases we were obliged for short lengths at such points to build up the outer edge of our road with a dry stone retaining wall, as in *Fig.* 2, *Plate* V. Again, it will be seen that by thus lengthening our line from the springing of the curve A to the end of the curve B, as in the continuous red line, *Plate* IV., we have descended vertically lower at the latter point than at the corresponding point of the dotted line, and then as we work on making extra length at each curve we gradually get more and more down-hill, and away from the dotted line, supposed to be laid out in the ordinary way. But the lower on the hill-side we get, the more do the spurs project and enlarge, so helping to lengthen our line. Thus it be will seen that by going to a little extra expense in lengthening the curves near the beginning, we may get on to easier ground sooner, and so in the end make the road cheaper. In this process of making length at Amba, we had to keep finding the length of our centre line by adding together the calculated lengths of curves and measured lengths of straights. And knowing this total length to any given point, say the end of a curve, we could at once tell how much the line had fallen vertically at the given gradient, and so what the formation level at that point should be. This gave us a fresh datum to work from in lining in the next straight and curve. Finally, by straining every nerve to make length between the ruling points, the pass X and the saddle S (*Plate* III.), we were finally able to cross the latter by an embankment 20 feet high (see *Figs.* 2 and 3, *Plate* II.), and so get to the north side of the spur-range. But even there we were not released from the necessity of working at our maximum gradient and keeping well out on spurs, and well in at hollows, for otherwise, owing to the slope of the edge-like top of the spur-range (see *Plate* III.), in the same direction as our road, our gradient line would have crossed this edge, and worked round back towards the main range, and so away from our destination. Fortunately we were saved from this by a long narrow spur, marked L on *Plate* III., projecting to the north and somewhat enlarged at its extremity. Our maximum gradient brought the trace, drawn out as I have described, just low enough to meet the neck of this spur. This neck might have been passed by a cutting, but bearing in mind the necessity of making length, the road was taken along its side, and at its extremity turned by a complete semi-circle of 60 feet radius and brought back along the other side of the spur. To effect this turn, the above semi-circle had at its commencement to be carried on a high embankment, which becoming lower with the gradient gradually died down, and the road ran into side cutting again on the further side of the spur. This detour gained a length of about 1200 feet, and the trace was therefore 60 feet lower on the far side of the neck than if it had been cut straight through. Thanks to the lower level thus reached, all beyond was comparatively easy, and at about the end of the third mile we were able to work at gradients easier than our maximum, and finally reached what might be termed the end of the mountain road at seven and a half miles from the top of the pass, having in that distance dropped more than 1800 feet vertically.

The laying out of the gradient traces and curves were not so easy as might appear from the plan, which does not show the thick brushwood and undergrowth with which all but the summits were clothed, and through which lines of sight had to be laboriously cut before each successive peg could be fixed. Nor does the plan quite help to realize the difficulties of finding a foot-hold for observer or instrument on the rocky precipices which intervened.

Balancing Cutting and Embankment.

It will be seen that on a mountain road like this the question of balancing excavation and embankment, usually dwelt on in the text-books on roads, can be but little considered. In an easier country this is, of course, a question to be settled, but never to the same extent as on a railway where the bulk of the earthwork is so much greater. Even in an easy country the increase of cost of carrying earth so limits the distance to which it can be advantageously conveyed, that usually the earth for embankments is cheapest got from alongside, and it would be worth while to increase the depth of side-ditches to supply it.

Cross Sections of Trace.

For the Amba Ghât road, cross sections were taken at every peg of the gradient trace, extending about 50 feet on each side of the line. Where the cross slopes were simple, merely their inclination was taken with a clinometer; but where precipitous, actual levelled sections had to be made. From these, after the adjustment of the centre line above described had been made, the quantities for an estimate were worked out by means of Bidder's Tables, which are based on the prismoidal formula (see also Molesworth's *Pocket Book*, or other books of reference). The calculations of the quantity of earthwork on most of the road estimates in our office had, however, been made by multiplying the mean of the end areas by the length, which, as you know, gives a quantity in excess of the true amount. With cross sections every 100 feet or so, and no two sections differing very much, the error was not very great, and as the native contractors believed in it, and thought the prismoidal formula only a method of cheating them, one was tempted to continue to use the simpler method.

General Remarks on Mountain Roads.

I have described the Amba Ghât road in detail, because it brings out strongly how important it is to gain length in order to ease gradient in working down a mountain side. Also, as an example of how advantage should be taken of spurs running in the right direction.

Further south, on the range of Western Ghâts, I had to repair a mountain road, which effected the descent to the low country by taking advantage of a long valley or ravine which broke back into the escarpment of the table land, a method equally advantageous as that of using the projecting spur, and which might be available where the other was not.

The trace of the Amba Ghât road was very much the same as it would be for a light narrow gauge railway, capable of working round curves of 50 feet to 100 feet radius. Of course, with a broad gauge all these small curves would disappear, and the line be cut through such small spurs and projections as the road wound round. And in surveying for such the eye would have to train itself only to see the larger features of the mountains, in fact, to see on the ground curves of 660 feet radius, or of 300 feet radius for the metre gauge, as a minimum, instead of curves of 60 feet, though the method of work would remain somewhat the same.

Older Practice.

I should here mention that the older Bombay practice in making mountain roads was not to trouble much about a minimum curve, or about curves at all, but having laid out a gradient trace down the mountain side, to cut a path along it, and then widen it out by cutting and embanking to the full width required. The angles were rounded off, those at the spurs by cutting in towards the hill from the path along the gradient trace; an operation very liable to make the formation too steep unless full allowance had been made in the gradient trace. And as a matter of fact, many of the older roads have short lengths steeper than 1 in 20.

It improves the appearance of every road to be laid out in true curves and straights, and where there are constant bends, as on a mountain road, they make it much easier and safer for traffic. Certainly every engineer who takes a pride in his roads, as most do in India, will go to the small amount of extra trouble in first lining out a road which it involves.

LECTURE II.

Cross Section of Hill Roads.

A controversy had long raged among Bombay engineers about the cross section of a road on a hill-side; one party being in favour of giving the whole surface an inward slope towards the inner gutter, as in *Fig.* 4, *Plate* VIII., while the other would give it the ordinary barrelled section, as in *Fig.* 3. Arguments in favour of the former are that the drainage of the outer half width does not spill over the embankment and destroy it; the inner gutter is ample to provide for the outer half width as well as the inner, together with that from the side slopes which it must also take. Finally, the great argument is that the inwards slope acts as does the cant or super-elevation on a railway curve, and makes the road safer for traffic. But experience in repairing hill roads (and I can here add my own), is all in favour of the level barrelled section, at any rate for roads not less than 16 feet wide. In a short time during the rains the section of the inwards sloping road is worn into the sort of thing shown by the dotted line in *Fig.* 4, and your road is scoured out into a regular water-course. The reason seems to be that the water falling on the whole width of the road has to run some distance along the road surface, following the steepest fall, compounded of the cross and longitudinal slopes, before it reaches the gutter. Traffic always has a tendency to clip corners and hug the inner side of a road curve, so that directly the wheels have at all broken the surface, there is all the water I have spoken of above to be caught by this broken surface, and to further scour it out; while from the section the road has now assumed it becomes almost impossible for traffic to avoid this damaged side of the road and use the outer half, see dotted line *Fig.* 4, and so it gets more and more ground down and scoured out. With the barrelled cross section this tendency of traffic may injure the inner slope first, but there is much less water to assist in the process, while if there are ruts traffic can easily keep further out to avoid them. The objection to the barrelled section that the road drainage would injure the embankment slope is met by making a small outer gutter which can be turned out at safe places, or at the masonry cross drains. A parapet wall or bank should with either section be made to prevent carts from running over the edge, and, as a matter of fact, traffic secures its own inwards cant on the barrelled cross section by hugging the inner gutter, which has in either case to be protected by guard stones. So much for hill roads.

Cross Section of Roads in easy Country.

On ordinary hard ground our cross section was as in *Figs.* 1 and 2, *Plate* VI.; in cuttings, as in *Fig.* 3. On the black or cotton-soil plains, as in *Fig.* 4, the whole length of road being embanked to at least a height of one foot six inches across the level, and to a greater extent where there were depressions. This kept the formation drained, otherwise the stiff clay into which water turns the black soil would swallow up almost any thickness of metalling. Even on an embankment it was as well to spread on the formation under the metalling a two or three inch layer of coarse sand, if it can be obtained near, as is often the case, from a river or nullah-bed. This sand was most effective in keeping the clay from working up through the metalling, and indeed on an unmade road, or where a road had fallen into a bad state, it was a specific to spread a layer over the clay, and thus prevent it from forming into ruts; the sand destroying the stiffness of the clay so that the traffic broke the ruts down. On this head I may further remind you of what your experiences of the "hards" made on the muddy banks of the Medway will have taught you, namely that there is nothing like brushwood to form the foundation of a road over a wet clay soil. Although we could not have afforded to use this over long lengths of black soil embankment, yet in specially bad places, where the clay remained wet for long after rain, it was worth while to use faggots of mimosa (thorny acacia) branches beneath the metalling. I have seen bad places on native tracks over the black soil only made passable by means of mimosa branches thrown loosely across.

But for the costliness of fuel, the black soil clay might be burnt and used to form a substratum, as is successfully done on clay soils in this country.

Side Slopes.

Where black soil embankments were exposed to inundations, the side slopes had to be made at $\frac{1}{2}$, and the sooner thorny acacia bushes could be induced to grow over them and bind them together the better under such circumstances. Elsewhere the usual slope was $\frac{1}{1\frac{1}{2}}$, which is about the natural slope of most dry soils loosely tipped.

Settlement.

In all cases the embankment should stand through one rainy season, in order to settle thoroughly before the metalling is spread.

Allowance for such settlement should be made in first making the embankment, the profiles being made higher than the final bank is intended to be, the usual allowance being one inch for every one foot of the intended final height.

Width.

And now as to *width*. Near a town where there is much traffic, fast as well as slow, a good wide road is of course necessary; for instance, the 30 feet which the text-books talk of. But away from the towns on these Deccan roads the traffic of the country is conducted by bullock carts, travelling at about two miles an hour, doing on an average 18 miles a day, and getting over as much as possible of that distance by night or in the early morning. Usually a long string of carts moves together, the drivers taking it in turns to lead, while those behind wrap themselves in their blankets and sleep on top of their carts. The patient bullocks conscientiously follow the tail of the cart in front, so that if the leading cart swerves to avoid a stone or newly mended place the whole line does the same, and on a wide road will meander from side to side like some huge crawling thing. Then if ruts or tracks have been formed these are scrupulously kept to, so that on a wide soft road you have the road-way cut up, as shown in *Fig.* 8, *Plate* VI., and I notice the same tendency even in the very different kind of traffic over English roads.

Now if your road is wide, and your allowance of money for repairs limited, your staff mend only the rutted track with broken stone; and even though rolled, the bullocks swerve from the mended portion and make another track, as dotted in *Fig.* 8, and you have a bad road for another year, and even when you have mended this you never get your road surface to its original even form.

The narrower the road is the less sinuous will be the course taken by the traffic, and the better state of repair you can keep it in for a given allowance of money.

The limit to narrowness is that two strings of carts should be able to pass each other with plenty of margin for bad driving and overhanging loads, and that I think is given by a width between gutters of 16 feet. The 18 feet width often laid down for second class Bombay roads allows for the eating away by rain of the sides of the metalling next the gutter, so giving a real available width of 16 feet, and is a safe rule. Twenty feet was laid down as the standard in the district I served in, while 24 feet was a standard width for the more important roads, where there was quick as well as slow traffic. The latter required more money for repairs to keep it in good order, and was, I think, as wide as was ever needed except in a town, or big European station. For comparison I may mention that the Dover road between Chatham and Rainham varies from 18 feet to 25 feet in width, and for a good deal of that distance averages 22 feet. The Chatham and Maidstone road from 15 feet to 20 feet. The Strood to Hoo road 16 feet to 22 feet The London to Richmond road, in the small portion still unaltered by building is about 26 feet wide. The London to Staines and Windsor road beyond Twickenham is for long distances only 18 feet wide. High roads in Gloucestershire, near Stroud, and elsewhere, are only about 17 or 18 feet wide. All the above widths are exclusive of side paths, and are from gutter to gutter, or where there is no gutter from edge to edge of metalling. In fact, I think not many high roads away from the neighbourhood of towns will be found in the South of England with a 30 feet width available for traffic, and all these evidently sufficed in width for a mixed traffic of quick and slow, even in the old pre-railway days, when they were the arteries of the national traffic. So that I think I am borne out in my preference for a width of 18 feet of metalling for ordinary Indian roads, and of 24 feet as an outside width for trunk roads.

Barrelling.

The English text-books preach against a highly curved or barrelled road surface, and no doubt it is an inconvenience, and possibly a danger, to quick traffic meeting from opposite directions; it may be a slight inconvenience too to slow traffic; but looked at from a road repairer's point of view it is a great advantage. It throws the water off at once, so that it does not stand in pools, and so help the traffic to churn the surface up into mud and ruts. It keeps the surface dry and hard, and by inducing the traffic to keep to the centre of the road it limits the surface you have to repair, and so for a comparatively small sum of money you can maintain a hard smooth track. A little-used road, where vehicles would not often meet each other, I should certainly make with as high a barrel as was consistent with vehicles passing each other at a walk, which would be the case with bullock carts, say up to nine inches for a roadway 18 feet wide.

Our specifications for new roads usually laid down that the barrelling was to be four inches high in the middle of a 20-feet road, *after* rolling and settlement of the embankments. To attain this it had to be six inches high when the metal was first spread on the new road. In the same proportion it would be five inches high for a 24-feet road, and only three and a-half inches high for an 18-feet road. But I myself do not think that in India six inches would be at all too much for an 18 feet road, and from a road repairer's point of view, I should be, if anything, inclined to increase it. The barelling might be an inconvenience to the occasional horse vehicle, but a soft cut-up road would be a still worse one. The best cross section for the barrelled surface is, I believe, that of two inclined planes with their meeting ridge rounded off, as in *Fig.* 7, *Plate* VI., but I cannot say I have tried it. The custom, and that is law in India, was in my districts to curve the surface to the arc of a circle. This makes the inclination unnecessarily steep near the edges, and this disadvantage is apt to be increased by the section being made too flat at the crown and too steep at the sides, thus practically getting a very narrow flat road. To avoid this, templates should be used in spreading the metal, and above all, care be taken to see that they are used.

A difference of opinion existed among engineers as to whether the barrelling should be given by increasing the thickness of the metal towards the crown, or by spreading a uniform layer over a curved formation surface. I myself incline to the latter, especially on an earthen embankment, as it gives inclined drainage surfaces below the metalling.

Metalling.

Roads in Bombay are popularly divided into "metalled" and "moorumed roads." The former are those of which the surface is formed of a layer of broken hard black trap rock, which makes a very hard and durable coating. The stone (I believe it is called "whinstone" where it occurs in England) breaks up into cubical fragments, of pretty much the same shape as those of the Kentish rag used in this neighbourhood, but it is blacker and very much harder and tougher. The only objection to its use is the hardness it gives to the road surface, which is trying to the bullocks' feet and legs, and a rider would not care to gallop his own horse over it. It is expensive because it can only be got from regularly opened up quarries, and these are necessarily not very frequent along the road, and the cost of carriage therefore mounts up; the cost of breaking the stone, which is done by hand with hammers, is also high. The usual specification is that "every piece shall pass through a ring of one and a half inches diameter," or "that no piece shall exceed one and a half inches in its greatest dimension." The coating was usually six inches thick in cuttings or on a hard foundation, and was, or ought to have been, *at least* nine inches on embankments. Where over six inches thick it should be put on in two thicknesses, each rolled separately.

Blindage.

To make the metalling bind and become a consolidated mass, sand and decayed rock (moorum), mentioned further on, was spread thinly over the surface during the process of rolling; preferably after the roller had passed over it once or twice. I have noticed near Chatham a clayey loam similarly used with Kentish rag metal, and apparently with good effect.

Curbing.

As the stones at the edges of the coating of metal would not be consolidated by the rolling if left loose at a slope, it was usual to confine them by stone curbing (see *Figs.* 2, 3, *Plate* VI.), which formed one side of the gutter.

Or it might be confined by a narrow edging of decayed rock (moorum) which consolidated better, as shown in *Fig.* 10. Earth, and especially clay, would be bad for this, as it would interfere with the drainage of the metalling into the side gutter, and the curb, though costly, was for that reason the better arrangement.

Metal in middle only.

Sometimes this moorum edging was made as wide as 4 to 6 ft., and only the centre portion of the road metalled (see *Fig.* 10, lower section, *Plate* VI.), a justifiable economy where the traffic was not great.

Moorumed Roads.

The higher ground, or uplands, of the undulating plain of the Deccan table land is formed of the exposed surfaces of the trap formation covered by the thinnest of soils, but for many feet in depth the originally hard black rock has weathered into a comparatively soft reddish brown mass, which can be readily quarried with the pick, and separates into cubical fragments, only the larger and harder of which need be broken with a hammer to enable it to be used as road material. This is known as moorum, and is the common road metal of the country, the harder coating being only used in large towns, European stations, and on important roads. As moorum is found at frequent intervals along most roads, this arrangement is a point to be remembered in laying out your line, and as it can be got within a foot or two, if not a few inches, of the surface by means of pick and mattock, it is of course very much cheaper than the hard stone metal, but is of course not nearly so durable and requires more attention to keep in good order. It is much easier for horses' and bullocks' feet. A layer six inches thick on a hard bottom, or nine inches on embankments or soft ground, was the custom. It required no sand or other "blindage" to make it bind, but consolidated well under a two or three ton roller drawn by bullocks. A very heavy steam roller crushed it to dust.

Rolling.

The practice of rolling road metal is, I see, much more common in England now than it was even 12 years ago, but still there are many roads where you will find patches of metal left to be rolled by the wheels of vehicles. In India rolling has long been considered an essential part of making or mending a road. In and about European stations and on important roads steam rollers were used, but more generally the work had to be done by iron or stone rollers drawn by bullocks, twelve being frequently yoked together as a team. Theoretically the weight on each inch of the width of the roller in contact with the metal should be as great as that to be expected on each inch of width of the most heavily laden vehicles using the road. These were ordinarily bullock carts, weighing about half a ton, except in the cotton districts, where the carts carried a much heavier load, on two wheels with tires about two inches wide, which would give about two and a-half cwt. per inch of width. This is just the pressure that a light steam 10-ton roller like that in the R.E. Park gives, and which you see is pretty effective over the Kentish rag on our barrack roads. Such might have answered for the moorum, but a 15-ton steam roller was more effective for the hard tough trap rock metal, though too heavy for the moorum. But practically where iron or stone rollers were used nothing like the above pressure was applied. The nearest approach was obtained by an iron roller of say two tons on three feet width, carrying a wooden frame above which could be loaded up with scrap iron to another ton. The pole for the first span of bullocks should be attachable to either side of the frame, so that the roller need not be reversed at the end of its roll, but the team of bullocks only turned and attached in the opposite direction.

Iron rollers were better than stone, as the latter had a tendency to tear up the surface of the moorum. The latter too were usually made too long and of small diameter, so that the weight was spread over too many inches. Metal and moorum were usually spread in the rainy season, as they require to be thoroughly wetted to consolidate under the roller.

Side-Path.

You will notice that in none of the sections drawn have I shown any side-path. These are only required in and about towns in India where there is quick traffic, and are not often given even there—for you will understand that on country roads, the chief traffic being by bullock carts travelling at two miles an hour, there is no need of pedestrians getting out of their way, and the latter get into the habit of walking along the middle of the road, and would not use a foot-path if it were made, which is an advantage as it would only make it more difficult to keep the surface drained.

Grass Road.

While speaking of the cross section and its coverings of metal or moorum, I should mention that in Upper Sindh, where the whole country is a flat plain of alluvial loam, and not a stone to be found for miles, the road surface is formed by spreading over it a layer of "moonj" grass, a long reedy grass something like the pampas grass of English gardens in appearance. The reeds being laid transversely to the direction of the road and then covered with an inch or two of loam. Without this the loamy soil gets cut up into a deep dust, and makes very heavy going for carts. As England's little wars so often take us into rainless sandy deserts, this method of keeping the wheels from sinking into the sand is worth bearing in mind.

Cross Section.—Military Roads.

In Southern Afghanistan the military roads were formed by clearing the surface of loose stones, or where they were in cutting by leaving the exposed surface. Among the hills the roads were chiefly up the torrent beds, and here, as well as wherever they skirted the hills, the soil was generally composed of limestone pebbles with the interstices filled in with loam or sand, and the surface, though rough and knobby, kept hard. Where the road passed over alluvial plains, in consistency pretty much like the soil of Sindh, the tracks kept multiplying one alongside the other, as one became ground up into deep dust the carts trying the fresh unbroken surface to the side. Unfortunately there were no reeds as in Sindh, or other plants to take their place in forming a road surface on such soil.

Bengal Roads.

I began my lectures by stating that different countries have different systems of road making specially suited to them. And at

Fig. 6, *Plate* VI., is shown the section used in Northern India, and taken from the Roorkee Treatise. My recollection of what I saw in those parts being that there was less embankment, and that usually the central metalled portion was narrower. This no doubt suits the loamy alluvial soil of the Gangetic plain, but that it does not suit the black soil plains of the Deccan I have seen proved at Indore, which is located towards the north of the trap area (see *Plate* I.), where a road made in this way was in a very bad state. The unmetalled side spaces impassable after rain, and the centre metalling almost swallowed up by the badly drained formation soil.

Gutters. (Ditches).

The ordinary section of gutter was as I have shown in *Figs.* 1, 2, and 3, *Plate* VI. On a steep gradient, unless the soil was very hard, the rush of water would scour out the ditches into small ravines, the cheapest way of preventing which was to put a stone or two across at intervals to form a dam (see *Fig.* 9, *Plate* VI.), so breaking the slope up into a series of nearly level reaches with a drop at the ends, or as on a hill road, the gutter might be roughly paved with flat stones. In making the gutters it must be remembered that vehicles often get off the road, and they should therefore not be so deep or steep-sided as to cause an accident.

On a hill road, where the outer edge is in embankment, the small outer gutter (see *Fig.* 5, *Plate* VIII.), should be stopped at intervals, and openings in the parapet made for turning it out, taking care to make a paved channel down the embankment to prevent its getting eaten away.

Catchwaters.

Where a road ran along a hill side, or indeed, wherever there was a cross-slope of the natural surface, a catchwater ditch had to be made on the upper side to prevent the flow of water from the country destroying the side of the cutting. These should be continued parallel to the road until they can be led into a water course, and so their water passed under the road by a drain or culvert. *Plate* VII. shows the catchwater of a hill road in plan, and *Figs.* 3 and 6, *Plate* VIII., in section. Some text-books lay down that they are to be traced as an inverted V above the road. In the case shown by the contours in *Fig.* 1, *Plate* VII., I should possibly trace them to form a very flat V, but on a more projecting spur as in *Fig.* 2, I should trace them as AB, AC. Here if traced to form a V its apex would lie above the dotted line BA'C, and it seems to me there would be very little water to catch, flowing, as it would, as shown by the arrows, down the steepest slopes to the water-courses. Their section would depend on the amount of water they were likely to have to carry, which on the hard bare uplands of the table-land was often considerable.

Catch-Pits.

On hill roads there was a rule (in Supt. Engineers' Circulars) that a catch-pit was to be provided above each drain or culvert (see *Figs.* 7 and 8, *Plate* VIII.), to catch stones or boulders brought down by the torrent, and which would otherwise injure the masonry and block the drain.

Guard-Stones.

Owing to the tendency I have before mentioned, of traffic to hug the inner edge of a curve, it is necessary in such places to place guard-stones of at least 9 in. × 9 in., or better 9 in. × 12 in. in section and standing up 18 in., to prevent the wheels from going over the edge of the stone curbing (where such is used) or into the gutter. On a hill road, as in *Plate* VII. (where the plan is taken from a circular issued by our Supt. Engineer, Gen. H. St. C. Wilkins, R.E.), at a spur the guard-stones would be on the inner side of the road, and at a re-entering angle on the outer side. Guard-stones are also required to protect the masonry parapet of a bridge from injury by cart wheels.

Fences and Parapets.

As a rule the Engineer had nothing to do with fencing his road, there being no permanent hedges grown, and fencing being made by the peasantry out of branches of thorny acacia from year to year. On the mountain roads, a common way of protecting the outer edge at dangerous places was to put in posts made of long rough stones. On the mountain road I described above the outer edge of the road was protected by a masonry parapet, where there was a foundation for it, *Fig.* 6, *Plate* VIII., or where it did not involve a serious addition to the embankment by an earthen bank reveted with dry stone, as in *Fig.* 3, *Plate* VIII.

Where the cross slope was so steep as to make this bank a serious addition to the earthwork, a dry stone wall might be substituted, of the same shape as the bank towards the road, *Fig.* 5, *Plate* VIII.

Dry Stone Walling.

On hill roads where owing to the steepness of the cross slope embankment could not be employed, and yet it was necessary to have the outer edge of the road out of cutting, the road was built up with dry stone walling (see *Fig.* 6, *Plate* VIII.); the rule followed being that the top should be three feet thick, the back vertical, the face to have a batter of $\frac{4}{1}$, the bed joints of the masonry kept perpendicular to the batter. Their joints were roughly dressed, and as long stones as possible used, set to break joint, and bond into the unshaped pieces forming the heart of the wall. The footings were cut perpendicular to the face batter.

The filling behind such walls had to be of broken stone, chips, or decayed rock, but not earth, which would have exerted more pressure.

Execution of Road Work.

Profiles.

The profiles for embankments were similar to what you have used for field-works, but made usually of bamboo; they should not be too far apart.

Cuttings.

For slight cuttings it was usual merely to set out the width of the formation, and then after it is excavated to the full depth to cut the side slopes, but where the cutting is deep its edges should be set ou from the centre line, and the sides of the cutting carried down at the proper slope by means of a batter-rule—a field-level would do. To set out these cutting lines, the cross slope at each peg of the centre line had to be measured. This can be done by means of a clinometer; it does not require much ingenuity to improvise one out of a piece of card-board and a plumb-bob. Then the slope of the ground being known, the widths from centre to cutting lines are found by the formula given in *Figs.* 1 and 2, *Plate* IX., which can be also found in Rankine's *Civil Engineering*, and the Roorkee Treatise. The dotted construction lines show how they can easily be worked out from the figures.

Earth-Work.

The method of execution of the earth-work is simplicity itself; the earth is dug with the ordinary pick, but instead of a shovel or spade being used, it is scraped with a mattock or hoe (No. 7, *Fig.* 6, *Plate* XII.), called a "phowra," into wicker or split-bamboo baskets, and then carried away by women. Where the lead is anything reasonable I do not think the method could be improved or cheapened. If wheelbarrows were introduced you would at once require strong men to use them, and the women's cheap labour would not be available. If the road is being excavated departmentally, and not by contract, some system of piece-work should be established ; or in certain cases, especially where time was an object, I found it very effective to pay each coolie woman by the number of basketfuls carried, a tin ticket being given at the tip for each one thrown, and these tickets were redeemed by money at the close of the day. Day labour, as everywhere, was slow and expensive.

As the price of earthwork rises so rapidly with increase in the length of lead, attention should especially be given to shortening this in attacking any large cutting or embankment.

Tip-Trucks and Rails.

Where the lead is necessarily very long, and the quantity of earth great, light tip trucks may be used economically, even with the cheap labour of India. At the Amba Ghât road they were used for the heavy cutting at the top pass and for the heavy embankment on the spur (marked L, *Plate* III.), but there was great loss of time in shifting the lines of rail. The De Cauville, or other systems of light steel rails of narrow gauge ready made up in lengths of straight, curves, points and crossings, etc., would have been invaluable.

Embankment measured by Excavation.

In contract piece-work it was advisable always to pay for embankment by measurement of the excavations made to form it. There is then no temptation to refrain from consolidating the embankment by trampling on it, which is one of the merits of this basket by basket earth movement.

Rock.

Cutting through rock was done by blasting with native gunpowder, a far from violent explosive, but which did not shatter the rock, and so enabled the fragments to be used for building. The blast holes were made by jumping with bars one and a quarter inch diameter, tipped with steel, or with what was very much better and saved blacksmith's labour in re-tipping the bars, steel bars of the same diameter. When these had worn too short they could be welded together to form a new one. Each jumper was worked by two men who could in hard black trap or basalt jump from nine inches to one foot in an hour. Water was poured down the hole from time to time to keep the tool cool, and assist in extracting the pounded rock by means of a ladle or scoop (No. 1, *Fig.* 6, *Plate* XII.).

The holes were tamped with dry earth or clay rammed home with a copper tamping bar, a hole for the priming being left by tamping round a brass needle. It was, however, infinitely preferable to use Bickford's fuze, which the natives soon learned to appreciate.

Masonry Works.

The most striking object in travelling along one of the roads I have been describing in the dry season, is the number of big bridges, not to mention culverts and drains, all spanning dry river beds and water-courses. These present a very different aspect during the rainy season when these beds are brimming over, and frequently their flood waters over-spreading miles of country. As an instance, there was the river shown at less than half-flood in the sketch on *Plate* XI., whose banks were some 40 feet on an average above the deepest channel, which in the dry season shrank to a brook one could step across, while in the rainy season it overflowed its banks, and in exceptional floods was 50 feet deep.

As to the culverts and drains over the lesser water-courses, owing to the hard barren character of the uplands where the soil after its first wetting allowed almost the whole rainfall to run off, what was a dry bed at one moment might an hour after be a raging torrent, deep and strong enough to carry away a man on horseback; one of these did sweep away an R.E. Sergeant on our staff, who with difficulty regained the bank with his horse after being carried a considerable way down the stream.

The masonry structures for passing the drainage of the country were known as *Drains*, when their openings were only two feet or three feet wide and spanned by stone slabs; *Culverts*, spanned by arches segmental or semi-circular up to 10 feet span, and for all spans beyond that as *Bridges*.

On *Plate* IX., is given an average example of a *slab drain*, with an opening of three feet span. Also of a *culvert* of five feet span. To find the waterway required for such a drain or culvert, the best plan is to roughly measure the area drained by the water-course it has to span, and then give sufficient opening to carry off a rainfall of four inches in one hour, which may be taken as a maximum. If possible, this should be compared with the highest flood that could be observed. Of course, rain did come down for a short time at a higher rate than above, but unless the drainage area was very small it took time to run off and through the drain, the case of an excessive but short rainfall on a very small drainage being met by its being of no practical advantage to make the drain of less opening than two feet wide.

The above calculation often corrected the erroneous idea one might get of a stream from the depth of the channel it had scoured out, especially where this was due to its steep fall. For instance, on the Amba Ghât road, in the original estimate made before the water-courses had been observed during the rains, judging by the depths of the ravines, bridges of 10 or 15 feet span were allowed for crossing formidable looking ravines, where it was found that a three feet slab drain would pass all the water, for the very steepness of bed which made the water scour out such a channel, carried it away in a smaller stream of a higher velocity than in a bed of less slope.

In such a case the sole of the drain had to be paved as shown in *Fig.* 7, *Plate* VIII.

Bridges.

A different plan had to be adopted for designing the openings of a bridge, as the above method would give an excessive width. The site having been chosen, the level of the highest known flood would be ascertained from the inhabitants, and compared with the highest flood that could be observed; and if the latter was alone reliable, or alone available, some margin of extra height would be allowed. A bridge with the springing of its arches one foot above such flood would be designed. And then sections having been taken, one say half-a-mile up-stream, or where a good average section could be got, free from deep pools or exceptional widenings, and another the same distance down-stream from the site, at both of which the highest point of the same flood as observed at the site would be noted, and the three sections connected by levelling. With these data the velocity (V) of the river in flood could be calculated, either by Bazin's formula given in Molesworth's *Pocket-book*, or by that given in the Roorkee Treatise. Then the afflux, or "rise due to obstruction," could be calculated by the formula given by Molesworth under the letter heading. If this rise exceeded what was thought safe for the local conditions, then the design had to be re-cast, either by adding additional spans, or by giving greater width to the spans. Such local conditions to be considered were the hardness of the river bed to resist the additional scour at the bridge caused by thus damming back the water, or the danger from raising the flood level over the country adjacent to the banks, for rivers obstructed in their own channel are apt to relieve themselves by eating out an entirely new one somewhere else. For instance, I have heard of one cunning stream which thus evaded, and left high and dry, two bridges built, first one over its original course, and then a second over the channel which it then made for itself elsewhere.

On a soft bed with the foundations depending on it, six inches would be the highest permissible rise, but on a rocky foundation even three feet rise might be permissible, if there was no danger from floods.

From the above it will be seen that the piers should be as narrow as consistent with proper strength, so as to cause as little obstruction as possible.

In large high bridges the shape of the piers was also governed by the consideration that the masonry should nowhere be under a greater pressure than it would safely bear, 20,000lbs. per square foot being the limit given by Rankine for the masonry of high dams, but which is rather high. Owing to the velocity of the current causing an overturning force, the masonry on the lower edge of the pier would be under greater compression than elsewhere, and if the pressure was calculated by the weight of the superstructure alone, a margin would have to be allowed for this increase.

In order to distribute the pressure in a high pier it was usual to give a batter on each face, of which the piers in *Plate* XI. are an example. This taper form also improved the appearance of the bridge.

Apart from the question of obstruction, it is cheaper and easier to build a large number of small arches over a given width of river than a fewer number of large ones, the limit in this direction being reached when each pier becomes more expensive than each arch.

Abutment Piers.

The thickness of the piers being determined as above, it is evident that they cannot be counted on for taking any of the thrust of the arches, and the thrust of each arch is balanced by that of the next, until that of the last on each side is taken by the abutment; so that if one arch failed, the whole set would fail too. To limit this risk, and also to allow the arches to be built in sets of so many at a time, it is usual, where the number is large, to build at intervals piers sufficiently thick as to serve as abutments if the arches on one side only are standing, and these are known as abutment piers.

When I joined the Bombay P.W.D., the standard authority for road masonry was a book published at Roorkee, and now out of print, though there is a copy in the S.M.E. Library, *Hart's Average Plans of Drains, Culverts, and Bridges.* These designs were used with, I think, a general understanding that the dimensions were all rather finely drawn, unless particularly good work could be obtained, and it was the practice to make everything a little stronger. Later on this practice was confirmed in the southern part of the Presidency by a set of circulars on roads, issued by Lieut.-General H. St. C. Wilkins, R.E., our Superintending Engineer, who has since embodied them in a *Treatise on Roads, Bridges, &c.*, (published by Spon), in which the various points one can only touch upon in a lecture are most fully discussed.

The proportions laid down in these circulars were as follows :—

Arches to be segmented.

Rise = $\frac{1}{4}$ span. Hart gives $\frac{1}{5}$th of span, and this was a very usual proportion. In the case of large bridges it kept down the height of the approaches required.

Thickness of Arch Ring (usually uniform throughout) is given by the table on *Plate* X., which I have taken from General Wilkins' Treatise, but differs a little from my copies of the circulars he issued as Superintending Engineer.

Hart's arch rings were all rather thinner. The formula given by Molesworth is empirical and rather vague, being : thickness at crown = $\cdot 35 \sqrt{\text{radius}}$ + a margin. Even Rankine gives only an empirical formula based on good existing examples. The above able gives a good margin of safety compared with either of these.

Thickness of Pier = $\frac{1}{6}$th span.

Thickness of Abutment at top = $\frac{1}{4}$th span. The back to have a batter of 1 in 8, best given by means of offsets.

Hart's proportions for the above were the same, but the back of his abutments were vertical, with a counterfort added if the abutments were high.

Loading or Backing of Arches.

In *Fig.* 4, *Plate* XI., I have showed what this would be by Rankine's rule, which is :—make the depth ($l\,k$) of the lowest point of the extrados left unloaded below its highest point (l) a mean proportional between the thickness of the arch ($m\,l$) and the radius ($o\,m$) of the intrados.

By Hart's rule it should be carried up, as shown in the same figure, to where planes inclined at 20° touch the extrados at e and f. Another rule is to carry it up to a point (ad), at a height above the centre of top of pier = $\frac{1}{3}$rd rise of arch $= p\,k = \frac{1}{3}\,p\,m$.

Practically, I think more than these was always given, as when drawn on a section they make the loading look so little.

Wing-Walls.

I have drawn those shown on *Plates* IX., X., and XII. for culverts and bridges in accordance with Hart's rules, but making the top thickness two feet instead of one foot six inches, which he gives, and which is hardly thick enough for masonry of the kind used. These were in general use, and more often, I think, with the increase I have given. Failures were seldom due to insufficient section, but to causes alluded to further on. Hart's rule in the case of bridges was thickness at top one foot six inches, front batter 1 in 12, and rear batter given in offsets 1 in 6. In the case of culverts, where, as a rule, the height would be comparatively low, he gives thickness at top one foot six inches, face vertical, rear batter in offsets 1 in 4.

General Wilkins' section, as given in his Circulars as Superintendent Engineer, was (as shown in *Fig.* 4, *Plate* XII.) thickness at top $=\frac{1}{10}$th height, face batter 1 in 6, rear vertical. If $\frac{1}{10}$th the height came to more than three feet, the excess length to be added in offsets to the rear, and keep the top only three feet thick.

In his Treatise the section is as above, with the addition of a batter of 1 in 12 in rear given in offsets. (Shown in outline on *Fig.* 4, *Plate* XII.) In either case the bed joints of masonry to be perpendicular to the front face. With Hart's sections it was usual to make the bed joints horizontal.

Wing-walls are, of course, retaining-walls, and except at their highest points surcharged ones, and can be calculated as such. If calculated for a stiff heavy clay, like wet black soil, it will be found that the last section is none too heavy theoretically, and I should advise the use of nothing lighter unless selected material could be used for the embankment behind.

A very common cause of failure of bridges was that the foundations of the wing-walls were not carried down to the same depth as those of the abutment, but stepped up the bank, as shown in dotted lines *a a* on *Plate* X., and similarly in *Figs.* 1 and 2, *Plate* XII., a proceeding only justified when the rock rose steeply too, which it seldom did on both banks of a river. Thus, owing to unequal settlement, the wing-walls either tore away from the abutment, or worse, levered it over by their weight away from the thrust of the arch, which then cracked and spread.

Carrying the wing-walls down to the rock gave an enormous mass of masonry buried in the bank, and I have seen various attempts to effect the junction of the abutment with the bank and approach embankment without wing-walls, but none were satisfactory, except where the bank rose steeply, as on the right hand side of the bridge in *Plate* X., where *return walls*, as shown, could be used to advantage, and even if the foundations, which if the rock did not rise were as necessary as for wing-walls, went as deep as those of the abutment, were economical where their length was less than their height; beyond that, wing-walls were cheaper. Curved wing-walls, as shown in *Plate* XI., have the advantage of giving a considerable amount of support to the abutment against the thrust of the arch.

Finally, they should be well provided with *weep-holes*, to drain the earth behind them, to further facilitate which they should be immediately backed by a layer of stones, or mason's chips. A clay embankment should be well wetted and trampled when filled in behind, as failures sometimes occurred simply by its swelling and forcing the wing-walls outwards. The safer and more economical method, however, would be to use only a selected material, even if nothing but burnt clay could be got to fill in behind the wing or return-walls.

Figs. 1 and 2, *Plate* XII., show the best plan for arranging the gradual diminution of offsets as the wall gets lower.

Execution of Masonry.

The method of quarrying stone I have before described. The masses detached by blasting were broken up by a heavy hammer, say of 14lbs. weight (No. 3, *Fig.* 6, *Plate* XII.), into the face of which was inserted a steel nose with blunt edge (No. 4, same *Fig.*), repeated blows of which along the same line split the stone into pieces more or less pyramidal in shape.

Face Stones.

For the *face stones* of the style of masonry commonly used, which may be described as rubble with a block-in-course facing (see *Fig.* 5, *Plate* XII.), the edges of the base of these pyramids were dressed to a certain depth in from what was to form the face. For good work this should be at least four inches, and for the large bridge shown on *Plate* XI. was six inches. This dressing was done with a steel tool, like a large cigar in shape, with the end brought to a flattened point (see No. 5, *Fig.* 6, *Plate* XII.), struck by an iron hammer with a cup-shaped face, into the hollow of which a disc of steel was sunk, (see No. 6, *Fig.* 6, *Plate* XII.) The courses ran from eight inches to ten inches in height. Care had to be taken that the face stones were alternately long and short, so as to break bond with the rubble masonry backing, as well as on the face of the work, with the stones in the courses above and below. The faces were left rough; "scabbled" or "rock-faced" would, I think, be the English term. Above all, it was important that the stones of the rubble backing should be well bonded, and set home by blows from a large wooden maul, to prevent the stones from resting on the mortar joints, in which case it would settle more than the block-in-course facing, and break away from it. To avoid such settlement horizontal courses of ashlar masonry were inserted throughout from side to side, at vertical intervals of six feet in the piers and abutments of the bridge in *Plate* XI.

Arching.

The arching in all good work was of stones, dressed to voussoir shape on all faces. Wherever else work is economized, it ought not to be in the arch-ring; and though in old days various abominations of "rubble arching" and other inferior kinds, with perhaps a ring of dressed stone on each face for appearance sake, but in reality to make matters worse by unequal compression, had been used, these are now all against orders.

Centres.

I have unfortunately kept no notes or sketches of the centres used for the arches of the larger bridges I saw built. Where the centres must be supported from the piers or abutments only, without any intermediate supports from the river bed, they require careful designing, and I can only refer you to Rankine's *Civil Engineering* and Tredgold's *Carpentry*, merely giving hints that the span to be bridged can be practically diminished by means of strong brackets secured by bolts through the pier, as in *Fig.* 4, *Plate* XI., and that support for such brackets, or even for the ends of the centres without brackets, can be got by building strong stone corbels into the faces of the piers and abutments, as shown in the same *Fig.*, which can, if thought necessary, be afterwards cut off. On *Plate* X. is drawn a centre for a 20-feet arch, the ribs, as shown, being put up five feet apart, with *lagging* across.

Centres for this and all larger spans were lowered by means of *sand-boxes*, which are much more satisfactory than wedges.

For small arches of culverts a common plan was to build up the hollow of the proposed arch solid, with stones set in mud with the top rounded and plastered smooth to the required intrados, as in *Fig.* 3, *Plate* IX.

As it was most important that the mortar should not have set when the centre was struck, so as to allow of its compressing and not crushing into powder in the joints, as the voussoirs took their bearing one on another, it was necessary to have all the voussoirs ready before the arch was begun, and then rapidly build the whole from both springings towards the crown, where the final course was cut to fit and driven home tight as a key stone.

Foundations.

Foundations were almost always carried down to the rock for large bridges, though small ones and culverts often stood on broad bases of concrete. My description of the rivers will have shown that, as a rule, there was little difficulty from having to work in water, for in the dry season the attenuated stream of even a big river could usually be diverted from one part of the bed to another. Pumping by steam had, however, to be resorted to to keep dry the pits for foundations sunk down to the rock through sand and alluvium, and the pits had often to be lined with sheet piling. In the case of a large bridge over the Krishna, built by Major Twemlow, R.E., where the dry weather stream was considerable, he extemporized an effective cofferdam by means of large brushwood gabions, four feet in diameter and six feet high, sunk in two rows down to the rocky bed round the site of foundation, filled with clay and the spaces between filled with the same. The water was then pumped out from the interior space.

Mortar.

The mortar used was moderately hydraulic, and made from the limestone nodules ("kunker") found in the black soil, though unfortunately rather sparsely, not as in Northern India where it is common enough to be used as road metal.

Iron and Wood Bridges.

I have said nothing about iron bridges or wooden ones, although they were occasionally used, first because the Deccan is essentially a "stone" country, but chiefly because I would never recommend their use for roads where masonry could be built nearly as cheaply. Both wood and iron have short lives compared to stone, and require constant attention from below as well as on the roadway. Thus an iron bridge may get on a railway where there is a numerous staff of skilled inspectors and mechanics, and where proper care is a matter of immediate life and death. But on a road in India there is great danger of neglect, and it is really cheaper to pay rather more, in cases where masonry arches are practicable, as first cost, than to have a large yearly expenditure on painting, scraping, and examining covered up bolts and rivets. And, moreover, in India a stone bridge does not often cost more than an iron one.

Cost.—The bridge shown on *Plate* XI. cost nearly £19,000 (taking 1R = 2s., which it nearly was at that time). The small bridge on *Plate* X. would cost about £1,500.

Roads such as I have described would, with their masonry, but exclusive of large bridges, cost from £500 to £1,000 per mile, according to the amount of the masonry. A hill road such as the Amba Ghât cost from £3,000 to £3,500 per mile.

W. W. R.

PAPER II.

THE SÛDAN MILITARY RAILWAY.

By Lieutenant M. Nathan, R.E.

I.—Construction and Maintenance.

A Railway to connect the Sûdan with Egypt was first proposed when Said Pasha was Viceroy. Mongel Bey reported on the subject, but the estimated expense was so great that the idea was for the time abandoned. A question of expense was, however, not likely to deter Ismail from giving his support to any scheme likely to bring Egypt and its "enlightened" Khedive more prominently before the eyes of Europe, and in 1871 the Sûdan Railway again came under consideration.

The original project was for a single line from Cairo to Khartûm, with a branch to Massowah. By this means the five transhipments of goods now necessary between the Sûdan and Lower Egypt would have been obviated, eleven million of Sûdanese brought into contact with civilization, and the greater part of the Red Sea voyage to India avoided.

This scheme was soon reduced to one for the construction of a line from Angash (Wady Halfa) to Matammeh (Shendy), a distance of 558 miles, and in 1871 the route was surveyed by Mr. J. Fowler, Civil Engineer, in detail as far as Hannek, and roughly on to Shendy. The southern terminus was selected as being the point where the camel routes from Abyssinia, Kedaref, Kalabat, Taka, Barraka, Sennâr, and other neighbouring fertile provinces converge; the northern terminus as being just below the Second Cataract and in easy communication with Cairo. The short four feet eight-and-a-half inch railway was already in existence for a distance of six miles on the right bank from Assuan to Shellal, round the First Cataract, and the Egyptian railway system extended as far as Siût.

After the commencement of the work the scheme was again modified, and a third project approved. This consisted of a line from Halfa, on the right bank to Koheh (160 miles), through the wild and rocky Batn-el-Hagar district. At Koheh, where the river is 700 yards wide, the railway was to cross to the left bank, and be continued to above the Third Cataract at Hannek (49 miles). From this place the river was to be used for traffic for 114 miles, as far as Abu Gûs, whence the railway was to be resumed for another 268 miles across the Bayuda desert to Khartûm. The total length of railway would thus have been 477 miles, and the estimated cost was £3,500,000.

The scheme was again modified by a government commission in 1881, which decided on a continuous line, 246 miles long, from Halfa to Dongola, whence river communication was to be used to Debbeh, a convenient centre of commerce for Darfûr, Kordofan, and the western provinces. A steam ferry was to be substituted for the bridge at Koheh.

Meanwhile a single line of three feet six inch gauge, with 50-lb. rails and seven-feet sleepers, commenced in 1873, had been completed, with 24 small bridges, from Angash (four miles north of Wady Halfa) to Sarras, a distance of 33½ miles, and the formation level (exclusive of bridging), to the 55th mile, *i.e.*, to eight miles from Ambigole. Here, after an expenditure of £400,000, the work had been stopped in 1877, at the commencement of a formidable rock-cutting, and nothing further was done to the line till the arrival of the English expedition, in 1884.

Early in September of that year the Sûdan Railway was taken over for the expedition by Major W. Clarke. Plate-laying was at once commenced at Sarras, with the material stored at that station, by a party of English and Egyptian Infantry, and native labourers. The 4th Battalion, Egyptian Army, was employed some miles ahead making up the banks where the old formation level had been damaged by floods.

The 8th Company, Royal Engineers, under Major Scott, arrived at Halfa on the 4th October. It consisted of five officers and 128 men, made up as follows:—

Construction section	49
Traffic department	28
Locomotive and carriage department ...	28
Clerks, storemen, servants, etc.	23
Total	128

The construction section, with the exception of six men left temporarily on the railway at Assuan and a few at Halfa for maintenance, were first employed in lifting and straightening the road from the $34\frac{1}{2}$ mile onwards, behind the plate-laying party, which had then reached the 36th.

On the 14th October floods breached the line at the 32nd mile, and at three places on the 37th, and the sappers were engaged on the two following days in making good the damage.

On the 21st, Major Scott took up the duties of managing director of the open line in the place of Major Clarke. The latter officer took charge of the extension work, and proceeded at once to survey a recently discovered route from the $41\frac{1}{4}$ mile of the 1871 survey, to the river between the Semneh and Wady Attireh cataracts. This route was five-and-three-quarter miles long, and presented no engineering difficulties beyond a deep cutting in sand, 3,200 feet in length. A line following it, to be completed in three weeks, was at first sanctioned by the General Officer Commanding Line of Communications, with a view to the whaler boats all being carried to Wady Attireh by rail and put in the water there, but, on it becoming apparent that owing to lack of labour and engine power the work would not be finished in time for this purpose, the project was abandoned, after the cutting had been commenced by the 4th Battalion Egyptian Army.

Meanwhile, plate-laying was going on under difficulties. No engines being available for the extension, trucks with rails and fastenings had to be hand-shunted from Sarras to railhead; sleepers were carried by 300 camels, and the coolie work done by 700 Esneh labourers—old men and boys. Nearly all these had deserted by the 28th October, when the extension works had reached the $39\frac{1}{2}$ mile, and plate-laying had to be stopped.

The extension, as far as it had been completed, was inspected on the 25th November, but found not yet fit for traffic, as, owing to want of material, spiking had not been completed, and joints were only single fish-plated; also the line required lifting and straightening throughout. This was done by 1st December, and the line opened from Sarras ($33\frac{1}{2}$ miles) to railhead ($39\frac{1}{2}$ miles) on the 4th. A dead siding was put in at the latter place, and the station called "Mohrat."

Since the arrival of the 8th Company, up to the date of opening the line to Mohrat, the average strength and composition of the working parties employed on the extension, in addition to the Esneh labourers mentioned above, were as follows :—20 Sappers, 8 men of the South Staffordshire Regiment, and 120 men of the 2nd Battalion Egyptian Army plate-laying, and 520 men of the 4th Battalion Egyptian Army at earth work.

On the open lines the bridges had been inspected and reported unsafe. In one case the bridge had been built on the chord instead of on the circumference of the curve on which it was situated. The improvements to seven bridges and their approaches (involving in the one above-mentioned some rock-cutting, and in most re-laying of the rails) were completed by 13th November.

Three maintenance gangs had also been established on the open line; they re-adjusted many sharp curves, removed excessive super-elevation, and tightened all fish-bolts. At Sarras a new siding was put in, a dead buffer fixed at the end of the triangle, and a coal stage erected. At Halfa the yard had been put in order and some points and crossings added.

At the end of November Major Clarke left the railway, and the Officer Commanding 8th Company became responsible for both open line and extension works.

An extension to $41\frac{1}{4}$ miles, where Major Clarke's proposed branch to Wady Attireh leaves the Fowler route, was sanctioned by General Buller on his way to the front on the 13th December, and carried out between the 15th and the 23rd. By the latter date the Wady Attireh diversion, which had again come under consideration, had been finally abandoned in consequence of a report from Captain Wilson, Superintendent of Works, that the cutting would require 500 men one month to complete, and of the fact that the track from Wady Attireh to Ambigole was unfit for camel convoy work. The extension was accordingly carried on along the old route and "Mohrat Wells" (47 miles), reached on the 18th January. A through and dead siding were laid here (old Mohrat station having been closed some days previously), and on the 21st a through train ran from Halfa to the new railhead. On the 29th plate-laying recommenced, and went on at intervals till 13th February, when the material stored at Halfa, and that which had arrived in driblets from Assuan, had all been expended. Railhead had then reached $50\frac{1}{2}$ miles. Sidings, as before, and a triangle were laid, and the line opened to the new station called "Ambigole Road" on the 21st.

The average strength and composition of the working parties on the extension from Mohrat to Ambigole Road were as follows :— 20 Sappers and 125 native labourers plate-laying, and between the 15th January and 13th February 250 men of the 2nd Battalion Egyptian Army repairing the bank.

While this extension was proceeding, a store for railway material was formed at Sarras, the triangle there re-laid, and a locomotive siding and ashpit put in. A siding had also been made at "Semneh Road" (37 miles), where stores for Semneh were henceforth unloaded, and a maintenance party for the open line had been kept up.

By the middle of February the expedition had entered upon another phase. Khartûm had fallen; an autumn campaign had been decided on, and it became necessary to make a further extension of the railway. Between the 9th and 19th February, Captain Wilson made a rapid survey across the desert, from railhead to Absarat, and recommended that the line should leave the route surveyed in 1871, just beyond the 53rd mile, and should go to Akasheh by Ambigole Wells and the desert, instead of by Ambigole and the river. The latter road is six miles longer than the other, and the heavy rock-cutting and other engineering difficulties made it impossible for a military line. From Akasheh it was proposed to follow the existing survey as far as Mograkeh, whence, instead of going to Koheh, *viâ* Amara and Sheikh Morgali, the line was to cross the desert to Absarat.

The extension to Ferket ($103\frac{1}{2}$ miles), was sanctioned on the 23rd February; 52 miles of permanent way material were at once ordered from England, and 300 plate-layers and mechanics from India, and the preparation of the formation level was commenced. As far as Akasheh it followed the general direction of the camel track, which, since the middle of February, had been used to convey stores to the front, but where this would have involved heavy earthworks and rock-cutting, as at the 63rd, 73rd, and 78th mile, considerable deviations were made, which increased its length by several miles. The greater part of the line was laid on the surface of the sandy and stony valleys, but where it crossed from one valley to another the ground was often very broken, and in four places it was necessary to survey accurately. These places, commencing at the 54th, 60th, $69\frac{1}{2}$th, and 72nd mile were called Nos. 1 to 4 cuttings, and in their respective lengths of 2,330, 7,800, 1,160, and 3,300 yards cutting and embankments were continuous, though rarely more than six feet deep or high. The cuttings were through shale and schist, and in a few places quartz rocks required blasting. After the sections had been plotted and carefully graded to avoid too steep inclines or very heavy work, sections were set up at 100 feet intervals, to guide the working parties. Between the cuttings the straight parts of the line were laid out with banderoles, and the curves with a theodolite, or by the method of offsets with 50 feet chords; the centre of the line was marked by cairns of stones and pickets, and the sides were spit-locked. Boning rods were used for filling in small dips or cutting through little knolls. Beyond Akasheh the formation level was made for seven miles over very rough ground, the Fowler plans and sections being followed with trifling alterations. Throughout the extension the steepest gradient allowed was 1 in 50, and sharpest curve of 500 feet radius. The formation level was made 13 feet wide, with the sides of embankments and cuttings sloping 1 in 2, except where the latter were in very hard soil.

Work was commenced at the four cuttings on 28th February, 14th March, and 19th and 2nd April; and early in March on the Akasheh-Ferket section. At the end of April all the cuttings had been completed, and the formation level finished up to $68\frac{1}{2}$ miles, and for five miles beyond Akasheh. At the end of May it was completed from railhead to seven miles beyond Akasheh; work on the Akasheh-Ferket section was then stopped 10 miles from the latter place.

Since the beginning of March an average of 1,200 Egyptian soldiers, from the 2nd, 4th, 7th, and 8th Battalions, had been employed on the earthworks of the extension. Each non-commissioned officer and soldier received three piastres ($7\frac{1}{2}$d.), for a day's work of over four hours, in addition to his regimental pay (one piastre for a private), and each native officer six piastres. The parties, as a rule, were allotted daily tasks by the superintending officers, and worked well. In the case of No. 4 cutting the average number of cubic feet of cutting and embankment per man, per diem, was 86, include cutting through some hard shale; in other cases this amount was exceeded.

While the formation level to Akasheh was in progress some of the Sappers had been engaged in hutting at Sarras, and railhead had been advanced to 52 miles by a party of Royal Engineers and Egyptian plate-layers, with some old material from Assuan.

In the second week in May the rails from England commenced arriving, and on the 14th the 300 native plate-layers and mechanics from India. Plate-laying was started on the 26th by 200 of this party, with 300 Egyptian soldiers of the 2nd and 7th Battalions for unskilled labour. The line, as already stated, was of three feet six inch gauge, with $41\frac{1}{2}$lbs. steel rails 24 feet long, fixed to nine rectangular six feet sleepers with dogspikes—four to a sleeper—and connected by fish plates, each with two bolts, except on curves where four were used.

The system of plate-laying adopted was roughly as follows :—

As soon as the material train, carrying about a quarter of a mile of permanent way, arrived, it was unloaded and the material packed on trollies by a party of Egyptians, 60 to 90 sleepers to a trolly and 30 rails to a pair. A small material trolly was kept as close as possible to railhead, being pushed forward as the joints (and round the curves and centres also) of each pair of rails were spiked. The remaining trollies followed immediately. The rails and sleepers were carried from them by parties of Egyptian soldiers—six men to a rail and one to a sleeper—and the latter thrown down roughly in position and then arranged by a sapper and four soldiers; the rails were placed upon them and the small material distributed by two or more men. Directly a trolly was emptied it was run back, being of course taken off the line if it met one with material.

The rails were placed in position, fish-plates put on, and bolts hand-tightened by a party of six Indians, accompanied by a man with a square who looked to the squareness of the joints. They were followed by six spanner-men who tightened the joints, and then came six sleeper squarers, two of whom marked with chalk upon the rails the position of each sleeper. Immediately in front of the material trollies were six pairs of spikers for the joints; round curves two extra men were put on for the centres.

Behind the material trollies were four more spanner-men, who finished up tightening the joints, and then 30 pairs of spikers. Each pair of spikers full spiked a rail and then moved on to the corresponding rail fifteen lengths ahead. They were followed by four rough straighteners and the rough packers, about 30 men, who packed the line sufficiently to allow of the material train passing over it. Then came another straightening party of four.

The full packing party of about 40 men followed about half-a-mile in rear; behind them were the final straighteners—four men—and some 80 Egyptians boxing up. There was also a jim-crow party of four men to take out bad joints.

The parties in advance of the full packers were under one civilian Permanent Way Inspector, and the charge of the line in rear of them, back to where it was opened for traffic, under another. The rate of advance was about half-a-mile in four hours, or a pair of rails in two minutes, and the daily progress regulated entirely by the supply of material, and that by the small amount of rolling stock and engine power available. After the first two days it was three-quarters of a mile a day through Nos. 1 and 2 cuttings, till railhead reached "Ambigole Wells" ($64\frac{1}{2}$ miles) on 13th June. The 14th and 15th were employed in laying a through end dead siding, and the line was opened to the new station on the latter day. Plate-laying was then stopped, by order of General Buller, while the main body of the expeditionary force was being passed down, and not resumed till the 22nd. It then proceeded at the rate of half-a-mile a day (except on Sundays, which were occupied always in shifting camp), through Nos. 3 and 4 cuttings to "Tanjour Road" (75 miles), which was reached on the 12th July. Camp was shifted on the 13th, and the 14th occupied in laying the usual sidings; the 15th was an Egyptian holiday, and no work was done. The next day plate-laying was started to Akasheh, and one mile laid in seven hours—between 5 a.m. and 12 noon.

On the 7th August, Akasheh ($87\frac{1}{4}$ miles) was reached; on the next day sidings were laid, and on the ninth a triangle at the $86\frac{1}{2}$ mile, where the line to Akasheh branches off from the formation level towards Ferket. On the 10th the first through train ran from Halfa. Gemai, Ambigole Road, and Tanjour Road stations were now closed, leaving only Sarras ($33\frac{1}{2}$ miles), and Ambigole Wells ($64\frac{1}{2}$ miles), between Halfa and railhead ($87\frac{1}{4}$ miles).

By this time it had been decided that plate-laying was not to go beyond Akasheh, but that the formation level was to be completed to Ferket. The Indian plate-layers, who had done excellent work, were sent home, and several of the Royal Engineer Officers left the railway.

Hitherto Captain Wilson had been Superintendent of Way and Works, assisted principally by Lieutenant Vidal. Captain Olivier, who came in charge of the Indians, superintended the plate-laying after their arrival. Lieutenants Hawkins, Roper, Nathan and Luard, and Mr. Gray Donald, C.E., had also been employed at various times on the construction of the line, and Royal Engineer Officers had been engaged at Cairo, Assuan and Halfa, in passing up stores and material for the extension. Colonel Wynne, Egyptian Army, commanded for some time the Egyptian troops employed on the work, and told off the working parties requisitioned for by the managing director.

II.—Working and Traffic.

The 8th Company commenced work at Halfa with five locomotives (Nos. I. to V.), of the old Sûdan railway. Of these No. I. was a saddle-tank, and the remainder 14-inch cylinder side-tank, single-bogie engines, of about 28 tons weight, with flangeless driving wheels. They had all six wheels coupled, but in every case, except that of No. V., the trailing rods had been removed, with the result of rendering the engines unsteady. They were of an inconveniently complicated form, and packed so closely that none of the parts could be got at except from a pit, and so were difficult to clean. Another objection to the type is the necessity for improvised tenders for journeys over 16 miles. The engines were further in a very bad condition, having been on the road and improperly cared for since 1873. Of the five, No. I., which had been brought up by a detachment of the company from Assuan, was in the best working order, and went on for a month without heavy repairs; it was condemned early in January. No. II. had also just come from Assuan: it broke down after three trips, and had to be thoroughly overhauled. No. III. was so bad that it was condemned on 6th October, after two days' work—broken up, and its parts used for keeping the others going. No. IV. required a large number of repairs before it was fit to run on 14th October. On 6th November it broke down and was condemned as past repair. No. V. was found lying dismantled in a ravine at Murshed (24th mile). It was the 19th November before it had been raised on to the line and sufficiently repaired to allow of its running.

With these engines the work was carried on till nearly the end of December, when the stores for the opening of the campaign had all been passed up. It had been necessary to keep reliefs of fitters at work night and day, overhauling engines at head-quarters, and for the 176 days' work that the five engines together had done there had been 90 whole days repairing.

The four engines (Nos. 9, 13, 7, 14), which had been ordered from the Cape Government at the commencement of the campaign, arrived at Halfa the 10th December, and 1st, 6th, and 15th January. They were six-wheel single-bogie tender engines, by Messrs. Beyer and Peacock, of estimated weight of 23 tons. They proved a very convenient class for a country where facility of cleaning is essential, and being capable of travelling longer distances without water than the Sûdan stock, were more suitable for the desert. They were old engines, but were in good working order when received. To disembark them the frames and boilers were packed up in the barges, and then hauled up an inclined tramway under a derrick, already in position at the head of the pier. They were ready for work on the 28th December, and 10th, 18th, and 29th January.

The Cape engines were not much worked until the extension beyond Ambigole Road was sanctioned; after that time they were constantly on the road.

When the extension was decided on in February, four new engines were ordered from England. Of these, two by the Hunslett Engine Company, Leeds, arrived at Halfa on the 21st June, and commenced working on the 11th and 27th of the following month. They were numbered 1 and 3, to replace the Sûdan railway locomotives of the same numbers. Both were four-wheel coupled bogie engines, estimated at 36 tons weight, with side-tanks and steam-brake gear. They had been designed for burning wood (probably in Norway), with long fire-boxes, low exhaust pipes, and bell-mouthed funnels, and were found to require some alterations before they could steam with coal. In both engines the exhaust was provided with a 6 inch wrought-iron nozzle; the internal funnel of No. 1 was raised 14 inches; No. 3 provided with the funnel from its Sûdan railway namesake, and was then found to steam very freely indeed. The chief disadvantages of these engines were their long wheel-base (seven feet rigid), considering the sharpness of the curves on the line, and the fact of the trailing wheels being close under the front of the fire-box, which caused the axle-boxes to run hot. Being landed in the middle of the hot weather, some difficulty was experienced in fitting the working parts, owing to their expansion.

The other two engines, numbered 10 and 11, arrived on the 22nd July, having come over the First Cataract instead of by the Assuan-Shellal railway. They had not started working by August 10th. They had been made by Messrs. Beyer and Peacock, for the Cape, and were very heavy, six-wheel coupled, single-bogie, saddle-tank engines with flangeless driving wheels, provided with two injectors instead of with pump and injector.

The four engines from England had been swung off the barges by high shears; owing to the deteriorating effects of the climate on ropes, it was necessary to employ very heavy purchases; a seven-inch heavy gun tackle rove in 22-inch blocks was used with crab winches.

Appendix I. shows the work done by the different engines from the time the railway was taken over by the 8th Company (4th October), to the date of opening the line to Akasheh (10th August).

When the 8th Company took over the railway, the rolling stock consisted of six brake-vans, each with one passenger compartment, five covered goods vans, and 50 open trucks. These trucks were all four-wheel, and had iron frames and sides, and wooden platforms. Their interior dimensions were fourteen feet by seven feet, and they were intended to carry five tons, though frequently loaded up to six or seven. Owing to the scarcity of carriages, troops had always to be carried on these trucks. The covered vans were converted into ambulance wagons, by being fitted with ropes for carrying stretchers according to Zavodooski's method (see Medical Staff Manual). A large number of sick and wounded were brought down in these vans, which were found to be comfortable.

About the middle of March rolling stock commenced to arrive from the Cape. The frames and bodies of trucks and carriages came out entire, the parts being packed in boxes. A party of infantry was employed in erecting the stock—under a locomotive foreman and an engine-driver, who came from the Cape with the engines, and had previously been employed in disembarking and erecting these. The Cape stock consisted of two 1st and 2nd class, and two 2nd and 3rd class composite carriages, four brake vans, thirteen open trucks, nine cattle wagons (of which two were converted into tank trucks) and one six-ton break down crane. The last, which arrived with the engines, was found invaluable both in erecting these and in lifting the bodies of carriages and trucks on to their wheels. All the Cape stock had wooden frames and sides; the majority of trucks and all break vans were provided with cast iron break blocks. It was not till the end of May that any considerable amount became available for traffic.

All repairs to engines and other stock were carried out at Halfa. An unfinished goods-shed, with temporary canvas roof, served as smith's shop; there were three forges here for doing heavy work, such as the making of switches and crossings, repairs to rolling stock, &c., one for keeping fitters supplied with split cotters and for any light work necessary, and one for the boiler maker. The service field forge was found too light to be of any use. A spring furnace was erected in the smith's shop for re-setting and tempering springs of rolling stock. The tin-smith also generally worked here, principally in making and repairing lamps, and in making oil cans, feeders, &c.

An existing brass furnace was used for casting brasses for the engines and for the repair of pumps. Considerable difficulty was experienced in moulding from the unsuitability of the sand on the spot.

The fitters' shop had a ten-inch and six-inch centre gap lathe, worked by a 10-horse power portable engine, and a circular saw was afterwards put up and worked by the same. A 14-inch centre gap lathe and a shaping machine were worked by hand.

Heavy repairs to engines were carried on in an engine pit (outside the fitter's shop), which had been provided with temporary canvas roof.

A running shed of rails, framed together with light iron and with a zinc roof on curved iron bars, was constructed as labour became available, between 12th February and 12th April. On one side of it was a lean-to, with thatched roof for a fitter's bench. Two engine pits were provided under shelter of the shed, and a third outside it.

When the 8th Company landed at Halfa there were eleven men for work in the shops. After the strength of the Company had been increased by the arrival of specially enlisted men from England, ten fitters, five smiths, one tinsmith, one boilermaker, two moulders, four carpenters, and five hammermen were employed.

The rolling-stock and shops were in charge of Captain Ferrier.

The engine-driving establishment of the 8th Company, on its arrival at Halfa, was nine engine-drivers, three firemen, and five cleaners. It was supplemented from time to time by men from the shops and by natives, employed as firemen. When the extension to Akasheh was decided on, thirteen more drivers, twelve firemen, and three cleaners were specially enlisted and sent out from England. As soon as a sufficient number of men had learnt the difficult road and the working of the locomotives, a double set of drivers and firemen was detailed to each engine, an arrangement necessary in a hot climate, with a limited number of locomotives; cleaners took the engines over on arrival and prepared for the road. Even after the old line had been improved, and the Cape and English engines had for the most part taken the places of the old and complicated Sûdan railway ones, the engine-drivers had still to encounter the difficulties of a line with steep gradients and sharp curves; a sandy country, in which it was impossible to keep brass bearings in order and prevent the different parts of the engine from getting clogged; a climate which rendered the work of pump and injector difficult; and bad coal.

The traffic was always worked on the "Line clear" system, which consists, briefly, in no station-master being allowed to start a train until he has received a telegraphic message from the next station, stating that the line is clear; also no engine driver is allowed to start his train until he has a certified copy of this message in his possession. The system worked perfectly.

The condition of the line and locomotives rendered it impossible for the railway to be of any great assistance to the expedition during October, 1884. Some Egyptian commissariat and miscellaneous stores were, however, taken to Sarras, including parts of the stern-wheel steamer *Lotus*. In the following month the greater part of the boat supplies and a considerable amount of commissariat stores were carried to Sarras, and a portion of the troops to Gemai. More commissariat stores and the remainder of the troops and boat supplies were carried up in December, and afterwards railway material for the extension, which had hitherto been carried on with rails hand shunted, and sleepers carried by camels from the store at Sarras. The line was opened for traffic to Mohrat Wells (39½ miles), 4th December, and on 24th December a station was made at Semneh Road (37 miles), from which stores were carried on camels to Semneh, there to be taken over by boat convoys.

Gemai (boat station), was closed at the end of December. During the first three months of 1885 the traffic returns show a falling off from those of the preceding month, the Expedition having all passed up and the means of forwarding stores from railhead being very limited. The traffic consisted principally of railway material for the extension and some commissariat stores; these were taken to Semneh Road for embarkation at Semneh up to the middle of January, when that reach was closed, and then to Mohrat; as railhead advanced they were taken to Mohrat Wells and Ambigole Road for embarkation, first at Ambigole (boat station), and then at Tanjour (boat station), till that reach became impassable towards the end of March. In April, the carrying power from Ambigole Road having been much increased, a large amount of stores were carried there for conveyance by the camel track across the desert to Akasheh (34 miles). Also stores were collected at railhead in view of the line being shortly required for carrying rails as soon as they should arrive from England. With the same idea, and to clear the Halfa yard, a depôt of sleepers was also formed at railhead. In June and July the traffic far exceeded what it had been on any previous month.

Not only were the troops of the Expedition carried down from Ambigole Wells or Tanjour Road to Halfa—between the 9th June and 25th July—but also all the railway material was forwarded for the extension to Akasheh.

Appendix II. shows the number of trains run monthly, together with the truck, passenger, and ton mileage.

Appendix III. gives the amount of stores carried for each department during the various months.

The constitution of the traffic staff varied from time to time, according to the number of stations open. It consisted of about 28 station-masters, shunters, pointsmen, guards, and clerks, under Captain Von Donop, as traffic manager, assisted after 26th May by Lieutenant Luard.

The work on the Sûdan Military Railway, for the Nile Expedition, may be summed up as follows:—The repair and maintenance of $33\frac{1}{2}$ miles of existing railway; the construction of $53\frac{3}{4}$ miles of new line through a nearly waterless desert, with no means of distributing material except the line itself; the transport, for the most part with limited and indifferent rolling stock, of about 9,000 troops round the worst part of the Second Cataract when going up the river, and round nearly the whole of it when coming down; and the carriage of 40,000 tons for an average distance of $36\frac{1}{2}$ miles.

In conclusion, it may be of interest to enquire generally into the future of Sûdan railways.

That which has been the subject of this paper will be of little use to commerce, unless constructed in a permanent manner to above the rapids at Hannek, a total distance from Wady Halfa of 205 miles.

To be permanent it must be kept out of the watercourses, and be provided with bridges where it is obliged to cross them. Once in every three or four years heavy rain produces floods, which would do great damage to the line as it at present stands.

Above Hannek, steam navigation, except at low Nile, is possible to Debbeh, a depôt for the commerce of the western provinces; and the railway constructed as suggested, would probably have the transport of this commerce.

This is, however, only the smaller part of the trade from the Sûdan. The greater portion comes down the many rivers of the eastern provinces, and collects at Khartûm. From there it goes by river to Abû Hamed, and thence across the desert to Korosko. This the railway would not affect.

Considering the comparatively small amount of goods likely to be carried, and the heavy cost of maintenance and working, it seems obvious that a Nile railway cannot pay as a commercial speculation. Politically and geographically it would tend to unite Egypt and the Sûdan, by bridging over part of the barren desert which separates them; but it has been determined that Egypt and the Sûdan, are, in future, to be independent of each other politically, as they have always been in every other respect.

Still the Sûdan may, when peace is restored there, be developed into a valuable possession for some European nation—the one that holds Suakin. For this the 260 miles of railway from Suakin to Berber must be constructed. Commercially, this line is likely to be a success; its expenses would not be so great as those of a Nile railway, and it would soon carry the whole of the Sûdan trade. Politically, while helping to separate the Sûdan from Egypt, it would tend to the safety of the latter country, by civilizing the tribes beyond its borders. To discuss what its other effects might be in opening up the interior of Africa, checking the slave trade, &c., would, however, be beyond the scope of a history of the Sûdan Military Railway.

Appendix IV. is a report of an Egyptian Commission on the commercial aspect of the question.

M. NATHAN,
Lieutenant, R.E.

AKASHEH,
10th August, 1884.

APPENDIX I.

ABSTRACT OF WORK DONE BY LOCOMOTIVES BETWEEN 4TH OCTOBER, 1884, AND 10TH AUGUST, 1885.

Nature of engine.	Distinguishing No. of engine.	Number of Days. At work	Not at work.	under repair.	Total.	Miles travelled.	Accidents. Breaks-down.	Derail-ments.	Other.	Total.	Remarks.
Sûdan Railway.	I.	82	2	10	94	3,983	3	2	...	5	Condemned 8th January, 1885. Fire-box cracked, and boiler dangerous.
	II.	181	13	114	308	9,889	6	2	...	8	Condemned 7th August, 1885. Fire-box cracked, and stays worn past repair.
	III.	2	...	1	3	133	2	...	...	2	Condemned 6th October, 1884. Broken up, and parts used to repair other engines.
	IV.	20	...	12	32	1,463	4	...	...	4	Condemned 6th November, 1884. Cylinder cover knocked out, and cylinder broken.
	V.	215	6	63	284	8,405	3	2	...	5	Shunting only after 8th July, 1885. Unfit to run on main line.
Cape.	7	165	26	15	206	8,419	1	...	...	1	
	9	180	25	6	211	8,827	1	1	...	2	Broke down on 28th July, 1885. Laid up for repairs.
	13	175	23	16	214	9,101	...	3	3	6	
	14	169	20	4	193	8,454	2*	...	1	3	*Train caught fire once.
English.	I.	26	...	...	26	1,552	...	...	...	...	Funnel, blast-pipe, and exhaust altered without laying up.
	III.	14	...	...	14	1,107	...	...	...	...	Altered as above in erection.
Totals		1,229	115	241	1,585	59,288	22	10	4	36	

APPENDIX II.

The following return shows the number of trains run monthly, together with the truck mileage, passenger mileage, and ton mileage:—

Month.	Number of trains.	Passenger mileage.	Ton mileage.	Truck mileage.
October	68	Not kept.	34,219	28,694
November	150	102,907	85,775	40,077
December	244	225,550	89,219	55,605
January	236	68,740	69,351	31,008
February	164	91,109	73,510	28,710
March	188	168,069	97,799	41,250
April	188	134,710	173,454	75,164
May	166	155,306	166,590	77,544
June	224	401,653	231,672	68,404
July	230	404,880	391,840	80,880
Total	1,858	1,752,924	1,413,429	527,336

APPENDIX III.

The following table shows the actual amount of stores carried for each Department during the various months :—

Month.	Commissariat.	Ordnance.	Whaler Supplies.	Egyptian.	Railway.	Various.	Total.
	tons.	tons.	tons.	tons.	tons.	tons.	tons.
October	324	10	92	236	53	321	1,036
November	590	15	1,584	17	25	422	2,653
December	1,036	55	670	267	690	1,271	3,989
January	666	65	...	385	1,078	817	3,011
February	310	105	...	287	1,795	185	2,682
March	533	165	...	305	1,002	906	2,911
April	1,500	155	...	525	1,492	1,162	4,834
May	938	45	...	362	1,450	936	3,731
June	202	55	...	225	3,289	957	4,728
July	1,101	494	...	87	6,982	1,132	9,796
Total	7,200	1,164	2,346	2,696	17,856	8,109	39,371

APPENDIX IV.

Report of a Commission on Sûdan Railways (1883).

The Commission appointed to report upon the best route for a railway to the Sûdan, having carefully considered the papers which have been submitted to them by the Council of Ministers, as well as other documentary and verbal evidence, have to report as follows:—

At the present time the Sûdan, although a dependency of Egypt, is so far removed—geographically by the obstructions to navigation in the Nile—that communication between the two countries is a matter of great difficulty, and it is universally acknowledged that steps must be taken as soon as possible to obtain an improved means of intercourse.

Three propositions have been made, with a view of attaining this end, which are as follows :—

1st. To construct a railway along the Nile, making the line either continuous from Cairo to the Sûdan, in prolongation of the present railway to Siût; or, in order to save a portion of the vast expense which would be incurred by the construction of so long a line, to utilise the portions of the river which are navigable, and to build the railway only where the Nile is dangerous or impassable for boats.

2nd. To make a railway from Suakin, on the Red Sea, to Kassala and Cos Redjeb on the river Atbara, and thence either direct to Khartûm or to Abu Harras, on the Blue Nile.

3rd. To make a railway direct from Suakin to Berber on the Nile.

The first of these proposals is that which found favour in Egypt during the reign of the late Khedive, and a very considerable expense has already been incurred in the construction of a portion of the line near Wady Halfa, and on the contract for the purchase of the railway material.

The main arguments used in favour of following the Nile Valley are, that Egypt would be put in connection with the Sûdan by a line wholly within her own territory; that there would be less risk of a foreign power interfering with the line of communication; and that the whole traffic of the Sûdan would necessarily pass through Lower Egypt. It is easy to understand the force of these arguments, and if the Nile Valley scheme were feasible, there would be a good deal to be said in favour of adopting this route.

A careful examination of the question tends, however, to show that the expense of making the line would be so great, and the cost of working it so excessive, in proportion to the traffic which could reasonably be expected, that the arguments against the adoption of this line are far greater than those in its favour. If the present line to Siût were extended to Shendy, a distance of about 1,800 kilometres, the work could not be completed for less than £8,000,000, If the line were made from Wady Halfa, the cost would be at east £4,000,000. If this part of the line only were built, it would be necessary for goods coming from the Upper Nile to be transferred from the river to the railway at Shendy, and back to the river at Wady Halfa; two more transhipments would be required at the First Cataract, and another change would have to be made at Siût, before the goods were finally placed in the railway wagons, which would bring them to Cairo or Alexandria. These numerous changes would cause such delay and expense that it is very probable merchants would continue to follow the comparatively inexpensive camel route from Berber to Suakin, and that the railway would not get enough traffic to pay expenses.

If, in order to encourage the use of the railway, the Egyptian Government were to raise the custom duties in the Red Sea Ports, the effect would be to check commercial enterprise in the Sûdan—the very thing which the railway is to be made to develope.

It was suggested by a Commission appointed in 1881, that in order to diminish the expense, the railway should only be constructed from Wady Halfa to Dongola; that the river should be utilised from Dongola to Debbeh; and that at the latter point a depôt should be formed, to which the Sûdan traffic would be transported on camels from Khartûm, Kordofan, etc.

This scheme might diminish the expense of the line, but would, however, be very unsatisfactory from a commercial point of view, and it would not be convenient for the transport of troops, as the tariff would be very high in consequence of expense of working being very great.

The Commission, therefore, feel it their duty to give a decided opinion against the construction of the Nile Valley railway, and they regret that a large sum has already been expended in the hopeless task of developing this route. To expend, however, on this account a still larger sum upon the construction of a railway, the prospects of which are so unfavourable, would, in their opinion, be a mistake from many points of view.

The second line of railway which has been proposed is one from Suakin to Kassala, Cos Redjeb, and Khartûm, or, as an alternative, from Cos Redjeb to Abu Harras, on the Blue Nile. The data which have been laid before the Commission with respect to the feasibility of this line, from an engineering point of view, are very vague, but it appears probable that considerable difficulties would be experienced in bringing the railway through the mountainous district north of Kassala, intersected as it is with numerous torrents, and also in crossing the country between the Atbara and Khartûm.

As the total length of the line would be over 1,000 kilometres, a moderate estimate of the total cost would be £3,500,000.

The main argument used in favour of this line is that the railway would pass through a comparatively fertile district, from which local traffic might be expected. The great object to be obtained is, however, to place Cairo in the closest connection with the Nile Valley and the Sûdan in general, and this would not be done with advantage by the formation of a roundabout railway to Khartûm through an outlaying district at a greatly increased cost.

It is to be hoped that this railway may also be built at some future time, and that the province of Taka may obtain the advantage of rapid communication with the outside world, but it would not be just to sacrifice the good of the Sûdan at large for the benefit of one district.

The Commission after due consideration, therefore, desire to record their opinion against the Suakin and Kassala line of railway.

The third and last proposal is for the construction of a direct railway from Suakin to Berber on the Nile. The length of this line would be about 460 kilometres; it follows the shortest distance between the Red Sea and the Nile, and reaches the river at a point where it again becomes navigable. Between Berber and Khartûm there is only one cataract, and those who have passed over it are almost unanimously of opinion that with a comparatively small expenditure it could be made navigable at all times of the year, thus placing Berber in direct water communication with the greater part of the Sûdan by means of the Blue and the White Niles.

The line of railway from Suakin to Berber presents no serious engineering difficulties, and it could probably be opened for traffic within two years from the date of commencing the work. The principal argument which has been used against the construction of this line is, that as it starts from a port on the Red Sea it would be easy for some other nation to interfere with the communication between Egypt and the Sûdan.

Without wishing to discuss this argument, the Commission must call attention to the very great advantages which would follow the establishment of a line of communication that would bring Khartûm within about eight days' journey of Cairo.

Another argument used against this line is that it would divert the whole of the Sûdan traffic into the Red Sea, and prevent its passing through Lower Egypt, but as the railway is more particularly required for the development of a traffic which now hardly exists—viz. : that of cotton, sugar, &c., from the Sûdan, this argument has no great force.

It must be remembered, too, that the saving which would be effected in the transport of troops and military stores would be very considerable.

It is probable that if the railway were now in existence the revolt in the Sûdan, which now gives so much trouble and causes such vast expense, might either not have occurred at all or have been suppressed at an earlier date.

The Commission have no hesitation in recommending that the line from Suakin to Berber be that adopted for the Sûdan railway, and that the work be commenced as soon as possible.

In conclusion, the Commission desire to record their opinion that the construction of the railway from Suakin to Berber is essential for the well-being of the Sûdan, and that it is important in the interests of Egypt herself that she should take the lead in its construction.

The Commission are of opinion that they should not pronounce on the political aspect of the question, as they are not sufficiently acquainted with the general policy of the Government.

(Signed) OMAR LOUTFI, *President, Minister of War and Marine.*

OSMAN RIFKI,
ABD-EL-KADER,
ROUSSEAU,
C. M. WATSON, Colonel,
MASON, Colonel,
C. H. RIGOLLET,
} *Members.*

WAR OFFICE, CAIRO,
24th June, 1883.

PAPER III.

LECTURE ON MARINE SURVEYING,

Delivered at the School of Military Engineering, February 2nd, 1886,

BY STAFF COMMANDER T. H. TIZARD, R.N.

IN LECTURING on Marine Surveying before the present audience, it will not be necessary to enter into the land part of the work, except to point out a few differences of procedure between our system and that of the Ordnance Survey. Nautical surveying consists in delineating accurately on paper, all that can be of use to the seaman in navigating his vessel into or out of the harbour, along a coast, or across the ocean ; the portion of land, then, that he requires represented on his chart, is always in immediate vicinity to the sea, and with the exception of a small tract near the coast, nothing detailed is required, all that is wanted of the interior being the position of such prominent objects as mountain peaks, churches, windmills, &c., as are visible from the ship. These prominent objects require to be clearly shown, and not choked by a mass of surrounding topography, otherwise the navigator has often difficulty in distinguishing quickly the particular object on the chart he requires. In the United Kingdom the whole of the land work is taken from the Ordnance Survey, all we do in addition being to omit all that is useless and to render prominent all that is useful to the seaman. Abroad we have nearly always to do the whole of the land work required as well as the soundings, and it may be readily understood that in many countries, still overgrown with mangrove brakes near the coast, and a virgin forest in the interior, our mode of procedure must differ essentially from that pursued in England, where a chain of triangles is extended from a base which has been measured with the greatest accuracy.

Briefly, our method is to do the whole of our work by angles, only measuring a comparatively rough base at first, either by sound, by micrometer, or, if practicable, by chain, in order to plot the work as nearly as possible on a given scale. Distance by chain for the details are not required, as these are put in by sextant and station pointer, so that the whole work is relatively correct, notwithstanding the fact that the scale may be somewhat imperfect. Eventually the scale is determined by astronomical observations at two or more points, and the accuracy is consequently only limited by the nature of the instruments used for this purpose. With the sextant and artificial horizon we consider that we can certainly obtain the correct position of the observation spot to within 100 feet, that is, supposing the level of the mercury in the trough is not subject to alteration by the attraction of mountain masses in the vicinity. Of course, the scale of the chart is only determined in this manner when the survey encloses a larger extent of coast; in harbour, or bays, it is generally practicable to measure a base by chain, which although not, perhaps, scientifically accurate, is practically so.

It sometimes happens that a running survey is required quickly for a particular purpose, when the details cannot be paid much attention to, as time only permits a short stay in the locality. The accuracy of the results will then all depend on the plotters, as the whole work has to be plotted after the place has been left, there being no time to do anything but out-door work on the ground. On these occasions our chief reliance is on accurate sketches taken on the spot, with the angles marked against every prominent mountain peak, tangent of an island, or point on the coast. It is evident that three or four commanding positions will cover in a large area of ground if they be judiciously chosen, the difficulty being afterwards to interpret the various sketches, as the plotter has only time to take up one position himself. This becomes a considerable difficulty when there are a large number of islands. Under these circumstances the plan I have adopted is to take up a good position on a commanding hill myself, and to obtain its height accurately; then, by means of angles of depression to every point on the coast, and to every tangent of an island, I have been able, knowing my height, to calculate the distance of each object I have obtained an angle of depression to, and so draw a rough plan from my own station alone; then the sketches obtained by the other observers are readily interpreted, and everything falls into its place without difficulty.

Having plotted on paper every prominent object visible from the sea we are ready to commence sounding, but before this can be done it is necessary to obtain tidal observations, as it is, of course, requisite that each depth taken should be referred to some fixed standard, and the height of the sea with reference to any standard is an ever varying quantity. The standard adopted by the Hydrographic Department of the Admiralty is the low waters of ordinary spring tides; this has to be ascertained for each particular survey, and the height of the tide registered at short intervals during the whole period the survey is in progress, so that tidal curves may be drawn which will allow the soundings as they are taken to be reduced to the adopted standard. In itself it would seem to be a very simple matter to ascertain the datum point of low water, but the rise and fall of the tide is influenced by such varying forces that it is by no means so simple as it seems. Theoretically, each tide rises and falls equal distances above and below a fixed line known as the mean level of the sea, which is always supposed to be constant, but in reality the mean level is subject to great variations: for instance, the atmospheric pressure influences it, for with a high barometer observation proves that the mean level will be lower than with a low barometer, varying about a foot in height for an inch of mercury, which is, of course, quite natural; again, the mean level is different at different seasons of the year, the difference in some places amounting to as much as two feet (notably in some parts of Australia); it is also greatly influenced, especially in estuaries or narrow seas, by the wind, and there are other disturbing causes which produce some effect, though comparatively slight ones. The first thing we do, then, is to ascertain the mean level of the sea for the particular period of the year in which the survey is extended, then by applying half the range of a spring tide to the mean level, we have the low water of ordinary springs. Of course, to ascertain with accuracy the mean level of the sea at any particular place, tidal observations should be taken day and night for at least a year; this is unfortunately rarely practicable, but in order to make surveys executed at considerable intervals of times comparable, it is customary to refer the datum adopted for the reduction of the soundings to some fixed point on the shore; for this purpose a rock that covers and uncovers at a given height on the tide pole is valuable; sometimes a mark is cut in on the rocky foreshore, and in this country the datum is referred to a dock sill in the vicinity, or to one of the Ordnance bench marks. Occasionally, with all our care, the mark is obliterated by lapse of time or other causes before a re-survey is required, then the only means we have of comparing the sounding is by again fixing, independently, the low water of ordinary spring tides, as already explained. For the purpose of taking tidal observations we have three descriptions of tide-pole, (1) a narrow strip of wood divided to feet and inches, which can be nailed against a jetty or post which does not dry at low water; (2) a hollow iron cylinder about two inches in diameter, with a screw at one end to screw into the ground when there is no pier or posts available; and (3) a pole which can be weighted at the bottom and supported by guys to anchors or stakes, for rocky ground, when it is not practicable to screw in an iron gauge. Each description of gauge can be lengthened to suit the range of tide at the locality of which observations are required.

The tide gauge is erected in a sheltered spot at as early a stage of this survey as is practicable, and observations taken day and night of the rise and fall of the tide, the height of the mercurial column being noted simultaneously. The mean pressure of the air is assumed as being equal to 30 inches of mercury, and an addition or subtraction made to the height of the tide on the pole according to the height of the mercurial column above or below this standard, one inch of mercury being assumed, as before mentioned, equivalent to a foot a water. It is requsite to register both day and night tides, as in many places there is a considerable diurnal inequality, and each high and low water must be in pairs to attain the mean level truly. Although on the English coast the diurnal inequality is for small amounts, on the east coasts of the United Kingdom being barely perceptible, and on the west coast about 18 inches, in many foreign ports it is so great that we often find it stated there is only one tide in the day, when accurate observation almost invariably shows there are two, although one of these tides perhaps only rises and falls as many inches as the other does feet. The diurnal inequality is also sometimes the origin of a report to the effect that the sea level is altering. It happened that such a report was made respecting the level of the sea at the Falkland Islands in 1874, and the *Challenger* was ordered to investigate this matter on her homeward voyage. Fortunately, Sir James Ross, during his celebrated Antartic voyages, had taken tidal observations and left permanent marks on the rocks at this group, and we were able to compare our results with his datum points. We could detect no change in the mean level of the sea when the usual allowances were made for barometric pressure,

&c., but our observations, as well as those of Sir James, showed certain irregularities of the tide which might easily be mistaken for a change of level by inaccurate observers. 1st, the diurnal inequality was considerable, on one occasion amounting to 18 inches at Port Stanley; that is a difference of three feet in the range of successive tides, the ranges of the greatest being only 7 feet. During the summer months the day tides are highest and have the greatest range, and during the winter months the night tides. 2nd, the atmospheric pressure, the range of which is very considerable, at the Falkland group exerts the usual influence on the mean sea level, which rises or falls universally with the mercurial column. It is, therefore, not at all improbable that occasionally during the winter months the residents at Port Stanley might observe during spring tides a high water that barely reached the ordinary mean level of the sea, for if, during this period of the year, when the day tides at springs have but a small range, a high barometer coincides with the period of greatest diurnal inequality, such a case would doubtless arise, and this has in all probability led the inhabitants to infer that a gradual alteration was taking place in the mean sea level.

Taking the tidal results in pairs, we find that supposing no abnormal winds have occured, a week's observations will give the mean level of the sea for the time of year at which the observations were taken, with considerable accuracy.

The datum to which the soundings have to be reduced having been explained, I will now point out the method of sounding—this may conveniently be divided into two heads, (*a*) the manner in which the depth is obtained, and (*b*) the method for fixing the position of the soundings.

First with regard to obtaining the depth; there are three methods depending on the soundings, one with the hand lead and lines, applicable to depths not exceeding 12 fathoms; another with the ordinary deep sea lead and line, applicable to depths not much over 100 fathoms; and lastly, ocean soundings, which require a special apparatus.

The hand lead generally used is 14lbs. in weight, and the hand line is marked at every foot up to 10 fathoms, above that to half fathoms. Soundings with this line are obtained as the ship or boat moves through the water by a leadsman swinging the lead a sufficient distance ahead to enable it to reach the bottom by the time he is over the spot where it entered the water; consequently the greater the depth, the further forward the line must be hove, and the speed of the ship slackened. It is customary to swing the lead over the head when this depth increases, to get a good momentum in heaving it forward, but personally I prefer having a heavier lead used (one of 28lbs.), so that the leadsman gets the necessary momentum without throwing it over head, and the lead sinks more rapidly to the bottom. The extra labour entailed can be readily met by having a man stationed to haul in the line.

When the depth exceeds 12 or 13 fathoms, and from that depth to 100 fathoms, the ordinary deep sea line is used with a valve lead of 56lbs. This line, which is marked at every fathom, is passed from the stern to the bow of the ship, the lead is then attached and hove overboard and a leadsman on a platform at the stern obtains the depth. Here, again, the speed of the ship must be so regulated that the man at the stern does not pass the spot where the lead entered the water before it reaches the bottom. In depths exceeding 40 fathoms it is better to stop the vessel and make certain of obtaining the soundings correctly. To facilitate passing the lead line from the stem to the bow, an endless rope is rove through blocks fixed to stanchions forward and aft, so that by bending the end of the lead line to the rope it can easily be hauled forward.

Both the hand and deep sea lines are well stretched before they are marked, and they are marked when sodden with water and kept in water and frequently tested. The nature of the bottom is in all cases ascertained and registered.

From the depth of 100 fathoms up to 500 fathoms we use the deep sea lines, with a valve lead of one hundredweight ; above 500 fathoms, the special apparatus for ocean depths, which consists—

(1) Of a series of iron sinkers, each weighing 56 lbs. ;

(2) Of a rod fitted with a mechanical contrivance for slipping the sinkers directly the bottom is reached ;

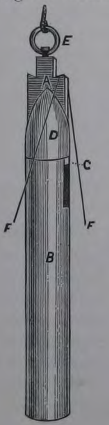
(3) Of a marked sounding line to ascertain the depth ; and

(4) Of an apparatus, arranged in the ship, to prevent sudden jerks on the sounding line from the pitching, or rolling, of the vessel.

(1.) The iron sinkers are cylindrical in form, and have a hole in the centre through which the sounding rod is passed, to prevent their swaying about, or getting detached, before the bottom is reached. On both sides of the sinkers, grooves are cut to take the wire by which they are suspended to the rod, and in order that these grooves may be in the same line when two, or more, sinkers are attached, studs, and corresponding hollows, are cast in the sinkers to keep them in place.

As a rule, six sinkers (3 cwt.) should be used; when, however, there is reason to suppose the depth will exceed 3,500 fathoms it would be advisable to use eight sinkers (4 cwt.), or when it is probable bottom may be reached with less than 2,000 fathoms of line, four sinkers (2 cwt.) will be ample.

(2.) The sounding rod is an iron cylinder with a butterfly valve at its lower end (to retain a specimen of the bottom), fitted with a mechanical contrivance for slipping the sinkers. This contrivance consists of a flat piece of iron, which slides in and out of a brass sheath on the upper part of the iron cylinder, the range of slide being regulated by a stud, which protrudes through a slit in the cylinder. On the top of this flat piece of iron is a ring, to which the sounding line is fastened, and just below the ring are two shoulders, over one of which the wire is placed that holds the sinkers. When the rod (and sinkers) is suspended by the sounding line, attached to the ring on the top of the flat piece of iron, these shoulders are exposed, but directly the tension of the line is relaxed, through the rod resting on the ground, the flat piece of iron descends into its brass sheath and conceals the shoulders, thus releasing the suspensory line and allowing the sinkers to disengage.

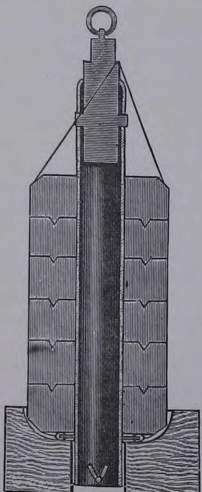


The accompanying figure shows the rod and the mechanical contrivance for slipping the weights.

A is the flat piece of iron; B the cylinder; D the brass sheath into which the flat piece of iron slides; C the stud and slit regulating the length of slide; F, F the wire passing over the shoulder; E the ring to which the sounding line is fastened. When the rod and sinkers are suspended by the sounding line the flat iron A is pulled out of its sheath D, and exposes the shoulders, the stud C being then at the upper end of the slit; directly the sinkers reach the bottom the sounding line becomes relaxed, and the flat iron A sinks into its sheath, concealing the shoulders, and consequently releasing the wire that suspends the sinkers, the slot C being then at the bottom of the slit in the cylinder.

The shoulders on the flat piece of iron should not be curved too much, or the wire, instead of being released, may be jammed by the V shape formed between the conical end of the brass sheath and the hollow of the shoulder, as the flat iron descends into the sheath.

The sinkers are suspended by a piece of No. 9 gauge wire, one fathom in length, the ends of which are passed through two small holes in an iron ring which slides on the rod below the sinkers, and twisted round their own parts, the bight of the wire being placed over the shoulder of the flat iron. It has been found convenient, in practice, to hollow a piece of wood to fit the bottom sinker, then to place on it, first, the ring with the line attached; second, the bottom sinker; third, the middle sinkers, and, lastly, the top sinker. The rod is then passed through the hole in the centre of the sinkers and the iron ring, and the bight of the wire placed over the shoulder of the flat piece of iron.



The annexed figure shows the rod, the weights, and piece of wood, &c., in section. The piece of wood should be fastened in some convenient place for sounding. It is, of course, understood that the ring, wire, and sinkers are left at the bottom at each sounding, the rod only being brought to the surface.

(3.) The sounding line is speedily perpared for the purpose; it is one inch in circumference, of the best Italian hemp, well hackled and rubbed down, and has a breaking strain of 14 cwt. The line should be marked at every 25 fathoms, the marks at the 100 fathoms being made with *blue* worsted tucked in and over the strands of the rope, one tuck for each 100 fathoms up to 1,000 fathoms, and then recommencing with one tuck for the 1,100 fathoms, &c. It will be found convenient if the 50-fathom intervals be marked with one tuck of *red* worsted, and the 25-fathom intervals with one tuck of *yellow* worsted. It is necessary to mark the line in this manner, rather than in the old-fashioned method with knots, to prevent its catching in the sheaves of the blocks as the line runs out, and also in order that the 100-fathom marks may be readily distinguished as they enter the water, so that the exact moment of entering may be registered.

The sounding line should be in one continuous length, and reeled up on one reel. It has been found (in practice) that the depth of the ocean seldom exceeds 3,000 fathoms ; this quantity of line, therefore, will be sufficient for all ordinary work ; but, as soundings have been obtained in 4,500 fathoms, in some particular localities, it is advisable to have 2,000 fathoms on a spare reel, ready to bend on should the depth be exceptionally great. The reel on which the line is wound should have at each end a disc of wood about $1\frac{1}{2}$ inches thick, with a groove cut in it, over which a gasket may be passed to check the revolutions when they exceed the speed of descent of the sinkers, otherwise the line is apt to foul. A reel to hold 3,000 fathoms will require to be about 5 feet in length, and if the heart, or roller of the reel, be about 6 inches in diameter, the line when wound up will be about $2\frac{1}{4}$ to $2\frac{1}{2}$ feet in diameter ; the discs, therefore, at the ends should be about that size. The reel should be hung horizontally, so as to revolve with as little friction as possible.

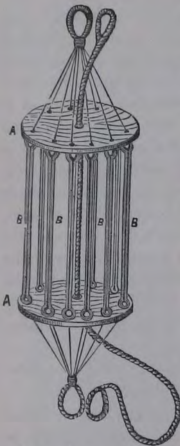
The first 50 fathoms of sounding line should be doubled to bear the strain of lifting the sinkers over the ship's side, &c.

(4). The apparatus in the ship consists of a set of indiarubber bands, technically termed "accumulators," to which a block is fastened through which the sounding line reeves. As the ship rolls or pitches these accumulators expand and contract, thus preventing sudden jerks on the sounding line, and so reducing to a minimum the chance of its parting. The accumulators are endless, with a wooden ring in each bight, kept in place by a small indiarubber band; to these wooden rings small lines are attached, which enables as large a number to be used as may be required. Ten are sufficient for sounding purposes.

A convenient method of fitting these accumulators is shown in the accompanying diagram.

A, A are two flat discs of wood with ten holes in each ; B, B, B, B are the accumulators. At each end of the accumulators a piece of cod line is spliced (into the wooden rings) and rove through the holes in the discs, when they are collected together and formed into a Flemish eye. To one of these eyes (the upper) a rope is bent, with which the accumulators are hoisted a sufficient height above the gunwale to allow them to stretch, and to the lower eye a block is hooked through which the sounding-line is rove.

The accumulators in their relaxed state are three feet in length; they are capable of stretching 17 feet, when they each exert a pressure of over one cwt.; beyond this they should not be stretched, or they are liable to carry away; when stretched nine feet they each exert a pressure of about 90lbs. To prevent their stretching more than 17 feet a 4-inch rope pendant, 15 feet in length, is passed through the centre of the discs, as shown in the figure, and the rope and blocks are attached to the eyes in this pendant as well as to the Flemish eyes of the accumulators. To keep the discs and accumulators in their proper places, the eye of the splice of the cod line, through the wooden ring of the accumulators, should be sufficiently long to pass through the hole in the disc and be toggled on the other side.

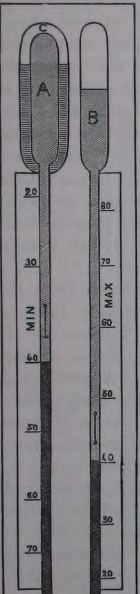


To render the accumulators so fitted, of service, they should be suspended either from a yard, or derrick, projecting over the ship's side, at least 25 feet above the deck to allow them to stretch freely.

In order to obtain the sounding correctly, steam-power is indispensable. In screw ships it has been found most convenient to sound from the central part of the vessel, suspending the accumulators from the main yard-arm; and in paddle vessels from the stern, suspending the accumulators from a derrick. In the former case the vessel must be kept steadily head to wind and sea, without moving through the water, and in the latter stern to wind and sea.

The rod and sinkers should be hoisted over the side by the sounding line, and as the weight of the sinkers is felt by the accumulators they will be found to stretch about six feet. The sinkers should be lowered carefully by hand for at least 200 fathoms, when the line may be permitted to run freely, care being taken that the reel does not revolve too quickly. As each 100-fathom mark enters the water the exact time should be noted, and the interval occupied by each 100 fathoms in running out thus ascertained. These intervals will be found to increase gradually, from about 70 seconds at 500 fathoms (that is, supposing three cwt. of sinkers be attached), to $2\frac{1}{4}$ minutes at 3,000 fathoms; directly, however, the weights reach the bottom, the time occupied by the line in running out increases to four or five minutes for each 100 fathoms, so that there can be little doubt that the sinkers no longer exert any influence, but that the line is merely running out by its own weight, and consequently that the bottom has been reached. The line should then be hauled in, and the specimen of the bottom carefully preserved, in spirits if possible, if not, it should be dried and kept in a meat or cocoa tin, a label being attached showing the date, position, and depth where it was obtained.

It is necessary to be very particular in registering the times of descent of the line, as the ordinary method of touch, is not applicable when the depth exceeds 500 fathoms.



Miller-Casella Thermometer on Six's principle.

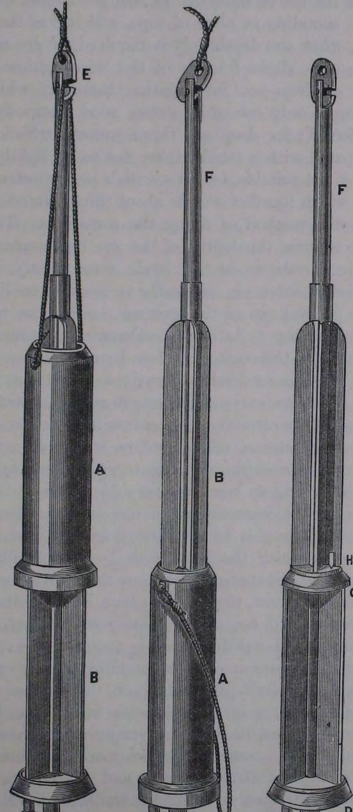
It may be interesting to mention that the deepest authentic sounding yet recorded is 4,600 fathoms, off the coast of Japan. The deepest obtained in the *Challenger* was 4,475 fathoms, in the western part of the North Pacific, and it took one and a half hours for four cwt. of sinkers to reach the bottom. To reach the bottom at 3,000 fathoms, about 50 minutes is required.

Whilst referring to ocean soundings, I may as well point out that we not only obtain the depth and a specimen of the bottom, but also ascertain the temperature of the water at the bottom, and bring up a specimen of bottom water for analysis.

The temperature at the bottom is ascertained by attaching a maximum and minimum thermometer to the lead line, a short distance above the sinkers. These thermometers are constructed on the design of Mr. Six, of Canterbury, and are furnished with a special appliance to prevent their being affected by pressure. The instrument consists of a curved tube, with a bulb at each end, the left-hand bulb A is filled with spirit, the expansion and contraction of which shows the temperature; this spirit is in contact with a small portion of mercury in the U part of the tube, which moves up or down as the spirit expands or contracts.

The right-hand bulb B is partially filled with spirit, and in addition has in it a small quantity of air at the pressure of an atmosphere, to act as a buffer on the mercury, so as to keep it always in contact with the spirit in the A tube, otherwise as the spirit contracted in the bulb, a hiatus might occur between the spirit and mercury. In each arm of the tube above the mercury is an index, shaped like a dumb-bell, the handle part of which is of steel, which, being pushed up on either side as the temperature increases or decreases, records the maximum or minimum reading. These indices have small springs attached, which press against the glass and prevent their receding with the mercury. The friction of these springs is overcome by the magnet when the instrument requires setting. Six's instrument, as originally constructed, required modification for ocean soundings, as the bulb A was exposed not only to the temperature, but also to the pressure due to depth, amounting to a ton per square inch for each 800 fathoms. Consequently, the results given were temperature + pressure. This defect has been remedied by a plan suggested by Mr. Miller, F.R.S., and instruments are now made with a subsidiary bulb C ending the primary bulb, which subsidiary bulb, being partially filled with spirit and spirit vapour, effectually prevents pressure acting on the primary bulb. Thermometers so made were originally constructed by Mr. Casalla, and hence are called Miller-Casella thermometers.

The water bottle used to obtain specimens of water from the bottom is an improvement on an apparatus, originally the production of a Swedish gentleman. It consists of a brass rod, F, with three radiating plates B, to strengthen it, and act as a guide for a brass sylinder, A, which encloses the water. At the bottom of one, half way down the radiating plates, are two finely ground sections of cones, C and D, and the brass cylinder is so arranged that its upper and lower interior surfaces fit with great accuracy on the cones, thus enclosing any water between them. At the top of the rod is a brass tumbler, E, with a slit in it, by means of which the bottle is suspended to the sounding line, and the cylinder suspended above the cones, whilst the bottle is descending. Directly the strain on the sounding line is released by its reaching the bottom, the tumbler falls over and releases the cylinder, which falling on the two cones effectually encloses the water. A tap, G, is fitted at the lower cone to facilitate drawing off the water, and a brass screw spile, F, on the upper cone. The woodcuts represent the bottle with the cylinder suspended; with it resting on the cones; and last without the cylinder.


E
F
F
A
B
H
C
B
A
D
G
6'
0'
SCALE
6"
1'

It is proper for me to state that of late years light wire has been used for ocean sounding in place of rope, and it has the advantage over the rope, when the depth only is required, of greater rapidity, owing to the very slight friction of the wire against the water. For purposes of deep sea investigation, however, which includes actual sounding as only one of its items, good hemp sounding-line is to be preferred; for deep sea thermometers, which have been carefully compared with a standard, are not to be lightly sacrificed, and the wire is not suitable for uses with a heavy water bottle and thermometer, which together weighs about thirty pounds.

Now as to the method of fixing the soundings. The object of sounding is to contour the depths of the sea in a similar manner to contouring the elevations on the land; consequently, a series of depths obtained at intervals, as nearly as possible on lines at right angles to the general run of the contours, enables us to draw the contours with accuracy. As a rule, submarine contours follow the general direction of the coast, therefore by obtaining sectional lines of soundings, at given intervals, as nearly as possible at right angles to the line of coast, we are enabled to get an exact section off the coast and draw in the contours. Of course it is very seldom a coast is straight for any distance, and, therefore, we lay off an imaginary line just inside the sinuosities of the coast, and measure distances along this line, putting up marks at every 50, 100, and 200, or more, feet, according to the requirements of the survey; then, by putting up marks at right angles to the line originally laid off, we get sectional lines on which the boat is to be kept whilst sounding. I may mention that the distances between the lines are only roughly obtained by measurement, their real position being plotted by angles to objects already fixed, for, as I previously pointed out, our work is all done by angles and rigidly relatively accurate.

To ascertain the position of each sounding on the sectional line, several plans are available, depending on the sizes of the survey. In very narrow rivers, or in places like the Suez Canal, for instance, we simply stretch a line, marked at given intervals, from one side to the other, and obtain a sounding at each mark, but this is naturally only applicable to very narrow streams and where there is but little traffic. In wider streams, or where the traffic is too great to permit a line to be stretched across, a pole of a given height is held upright on the bank of the river, and a table of angles at given distances from the pole is prepared; then the angle for each distance off the pole where the sounding is required is placed on the sextant, and the sounding obtained when the pole subtends that angle, the boat being also on the line of transit of the two marks.

When the river is too wide to permit of this mode of procedure, or off a coast, the soundings are fixed by station pointer angles to objects previously plotted on the chart; care being always taken that the angles shall be of such a nature that they will readily fix the position of the sounding. This is an independent means of obtaining the boat's position, and should plot on the sectional line the boat is sounding, so that we check at every point the correctness of the work.

I have explained now how in large scale survey we ascertain the positions of the soundings, but in scales of less than ten inches to the mile we do not often find it necessary to place marks for the sectional lines; as a general rule there are sufficient natural objects for the purpose, and it is in rapidly seizing hold of these objects, and rigidly keeping the boat on their line of transit, that practically tests the nautical surveyor. The mode of doing this is to fix the position of the boat as she pulls along the shore, by sextant and station-pointer angles, until the spot is reached where the sectional line is required. The position of the boat being plotted on the chart and the line of direction of the section drawn, the angle is taken off between it and a well-known object already on the paper; this angle is placed on the sextant, and the instrument is moved until the well-known object is seen reflected through the tube; the object it is then seen in line with, will, if kept in transit, lead the boat along the section it is desired to run the soundings on, the line being fixed as before mentioned by angles to points already plotted on the paper.

Occasionally, off a flat coast, it is found impracticable to run sectional lines of soundings, as there are no back objects; the system then pursued is to steer by compass and fix by sextant and station-pointer as before. It is quite as accurate, when complete, as any other method of getting soundings, but is far more difficult, as the varying strength of the tidal stream renders it almost impossible, even with the greatest skill and experience, to prevent the ship or boat being set off the line it is intended she should be on, and, consequently, a longer time is required to sound over a given area than when we are able to obtain sectional lines by keeping two objects in transit.

Occasionally, banks are discovered in the ocean, or, at any rate, out of sight of land, and their extent and nature ascertained. Our mode of procedure is then to either drop a mark buoy, or to anchor the ship directly a shore sounding is obtained. Usually the ship is anchored, if the wind and weather permits, and her position obtained by astronomical observation. She thus becomes the first starting point in ascertaining the extent of the shore. The boats are sent to sound in every direction round the ship, the soundings being plotted by bearings of, and masthead angles to, the ship; and depths have been obtained in this manner for a radius of three miles round the vessel. The circle round the ship being completed, the general bend of the bank in her vicinity can be ascertained by the contour lines. A boat is now sent in a given direction for a distance of about three miles, and anchored. When in position her bearing is obtained by astronomical observation from the vessel, and her exact distance by firing guns. The ship now drops a buoy in the position she occupies, and gets under weigh and takes up a new position about three miles on the other side of the boat at anchor, the distance from, and bearing of, the boat, being again ascertained, the former by sound, and the latter by astronomical observation. The new position of the ship is then sounded round, and she is again and again shifted until the whole extent of the bank has been ascertained.

At each station the ship occupies, her position is determined independently by astronomical observation, so that there shall be no error; and finally, by returning to the mark buoy left at her first position, rates for the chronometer may be obtained, and any error in those instruments guarded against.

It will be evident from the foregoing remarks that our chief dependence in nautical surveying is on the sextant. That is the instrument which enables us to perform our work accurately, and with it, and it alone, many valuable surveys have been made. The great disadvantage of the sextant is that it has to be put down each time an angle is registered, as it is not practicable to hold the instrument and write down at the same time; so that it is very convenient to have some one to register the angles as they are observed; otherwise, it is, I think, the best instrument there is for surveying, for the theodolite, altazimuth, or transit instrument, are only of use on shore, and the compass is subject to so many errors that observations by it alone cannot be relied on; but with a sextant the whole work of either a land or marine survey can be executed with the greatest precision.

This instrument being then so useful to us, it is important to know its errors. Most of these are doubtless familiar to every one who makes use of the sextant, but there is one very important error which seems to have attracted very little attention, and that is the error of centering.

All sextants have an error of this description, and in good instruments it is usually progressive; being nothing at the zero of the instrument and increasing gradually with the angle, sometimes amounting to 50″ or 60″ at 120°. If it does not so increase, or if it varies, it shows that in all probability there is an error in the graduation as well. These two errors cannot be entirely separated, but the graduation can be tested by trying the vernier at different parts of the arc, when, if the graduation is correct, the zero and last division in the vernier will invariably cut lines on the ark simultaneously.

The plan I usually adopt to obtain the errors of centering is either to measure angles between objects on the land by it, and by Bordas repeating circle, or else to obtain a series of equal altitudes of the sun at all elevations, when the observations, worked as single altitudes, should agree with the results given by the equal altitudes. This is seldom the case, but it will be found that the mean result of the a.m. and p.m. sights always will agree. Consequently, by applying an error to the altitudes until the result agrees with that obtained by the equal altitudes, the error of centering at that altitude is obtained. Then by obtaining a series of results at different altitudes, and drawing a curve of errors, the amount at any altitude or angle can be tabulated. Lately, the authorities at the observatory at Kew have undertaken to test sextants for errors of centering by payment of a small fee, and it would be well before purchasing any instrument to ascertain that its valuation has been so tested, and to get a copy of the Kew certificate attached to the receipt.

T. H. T.

PAPER IV.

DEMOLITION OF RUINS OF POOR HOUSE, HALIFAX, N.S.

Description of Ruins.

This poor house was destroyed by fire during the autumn of 1882, with the exception of the exterior walls and two of the main partition walls. During the winter succeeding the fire, a large portion of the wall on the southern side was blown down by a gale, and during the following summer a considerable portion of the wing on the same side had been pulled down by hand. The remaining ruins, however, were too firm to be moved either by hand or weather, and the Commanding Royal Engineer was then asked by the Dominion Government to take the demolition in hand.

From the plan and views accompanying this report, *Plates* I., II., and III., a good idea of the state of the building at the commencement of the operations can be obtained. The unshaded portions of the walls on the plan were the portions that had been previously removed.

On the night of the fire, the wind had been from the North-west, and consequently the walls on the southern side had been considerably weakened; but those on the northern side were in a good state of preservation, and proved their tenacity in a wonderful manner during the operations.

Construction of the Building.

The outer course of the exterior walls (*i.e.*, to a depth of four inches) had been built in cement (one of cement to three of sand); the remaining courses, as well as the partition walls, were built in mortar (one of lime to three of sand). The exterior walls, with the exception of those of the square towers, were twenty inches thick (*vide* plan). All through the building there were strong courses of granite stone, laid in cement. A span of twenty-nine feet, with a great weight of brickwork overhead, including a chimney stack, retained its position in a most remarkable manner.

Season of the Year.

The greater part of the operations were carried on during the months of frost, and the fact that most of the walls were coated on one side with half-an-inch of solid ice, greatly assisted the walls to withstand the explosions.

Preliminary Experiment.

The wing on the south side was first experimented upon, in order to form an estimate for the demolition of the entire ruins. This estimate was given at 317 dollars, including the expense of the experiment. The total cost of the operation to the Dominion Government was 316 dollars.

Form of Explosives.

The charges for the first ten explosions were made up exclusively of dry nine-ounce discs, but for the remaining charges $2\frac{1}{2}$-lb. slabs had to be used principally. These slabs were issued wet, and had to be dried before being used. They were also bored for detonators, and cut in many cases into halves and quarters. A few charges were made up of dynamite, purchased locally; one of gunpowder, and a few of granulated guncotton.

A "quantity dynamo" was employed to ignite the first few charges, but the remainder were all fired by a battery of Leclanché's firing cells.

Failures, and Causes thereof.

In a few cases some of the charges in a circuit did not detonate, the charges and detonators being perfectly intact after the explosion. In these cases the failure was due to difference of sensitiveness in the detonators, the too sensitive detonators breaking the circuit before the others had been heated sufficiently to fire the explosive composition.

In other cases the guncotton burned without detonating. It appeared to the officers conducting the operations at first that this was the fault of the detonators, but at the end of the operations they were convinced that in these cases the guncotton had not been dry enough, and that this was the only cause of the failure. The guncotton was dried in front of a close stove, and although it was weighed, and was to all appearances sufficiently dry when first dried, it must have absorbed moisture during the intervals between the explosions, and also from rain and damp during transport to and from the building.

The amount of explosives used was as follows :—

Guncotton	...	...	458lbs.	1oz.
Gunpowder	...	...	100	0
Dynamite	...	...	25	0
Granulated guncotton		...	26	0

Detonators.

No. 12 low tension	...	...	169
Dynamite	...	...	27

Gun Tubes.

No. 10 low tension	...	...	6

The amount of each charge varied, of course, with the amount of work that had to be done, and will be a matter for calculation in future cases, but the arrangement of the charges, in which considerable improvements were made as the work was carried on, must be similar on future occasions, and are, therefore, worthy of notice.

No. 1 explosion consisted of several charges of guncotton placed at intervals and packed into priming charge tins, each ignited by one or two detonators (see *Figs.* 1 and 2, *Plate* IV.), and were placed in holes in the wall.

Nos. 2, 3, 4, 5, and 6, were similar to No. 1, but varied slightly in the quantity of explosive used. No. 7 consisted of 4 charges of twelve discs, each lashed together, as shown in *Fig.* 3, *Plate* IV., and placed on a wooden shelf inside the eastern tower; total charge, 27lbs. of guncotton.

Nos. 8, 9, and 10 similar to No. 1.

No. 12 consisted of guncotton made up of slabs and discs, as shown in *Fig.* 5, *Plate* IV., and was placed against the brickwork.

No. 13 consisted of several charges made up as shown in *Fig.* 5, *Plate* IV., and one charge made up like *Fig.* 6, *Plate* IV., as it had to fit into a corner, and were fixed in holes cut in the wall.

No. 14 consisted of guncotton slabs and half slabs, extended at intervals over a long length of wall, each fired with a separate detonator.

No. 15 consisted of two charges of guncotton, supported on the end of poles, as shown in *Fig.* 11, *Plate* IV., and one placed in a hole.

No. 16. This explosion was arranged with dynamite filled into priming charge tins, each fitted with a detonator (see *Fig.* 12, *Plate* IV.). The charges were placed in holes 4 inches deep cut in the brickwork.

No. 17 consisted of dynamite filled into two tins, with a primer in each tin; these were lashed to the end of a pole and placed against the wall (see *Fig.* 13, *Plate* IV.).

Nos. 18, 19, 20, and 21 were similar to No. 15.

No. 22 consisted of charges of guncotton composed of slabs and half slabs fixed to a board to keep them in position, one dynamite detonator being inserted into each of the half slabs. (See *Fig.* 16, *Plate* IV. for half slabs, and *Fig.* 17, *Plate* IV. for whole and half slabs).

Nos. 23, 28, 29, 30, and 31 were similar to No. 22.

Nos. 32 consisted of guncotton slabs placed in the crevices made by previous charges.

Nos. 33, 34, 35, 36, 37, 38, and 39 were similar to No. 32.

General Remarks.

The granulated guncotton proved itself most suitable for demolitions of this nature, and gave most satisfactory results. It was used pressed in priming charge tins, with detonators placed in the centre. The dynamite was not easily handled, owing to the extreme cold during the operations. No. 12 low tension detonator, although most effective, is an expensive item in a small charge, its cost being about 11d., and it is suggested whether it would not be worth while considering the question of having a smaller detonator of similar pattern, to be used with charges not exceeding $2\frac{1}{2}$lbs.

The detonators purchased locally for the dynamite cost less than 4d. each. They were found to be effective with guncotton, and they also had two leads attached, four feet long, watertight, most convenient to handle, and made good joints. The dynamite was supposed to contain 75 per cent. of nitro-glycerine.

The result of each charge is not of much lnterest, but the general experience from this demolition is that it requires $1\frac{1}{4}$lbs. of guncotton per foot run to cut through sixteen inches of brickwork —slightly larger charges than laid down in *Instruction in Military Engineering*—and that in using half slabs of guncotton, the most convenient method is to place three half slabs in contact (the centre one with a detonator); and for long longitudinal cuts, charges at intervals of eighteen inches, using nine-ounce discs. A charge of four discs will destroy about two feet, measured along the face of a sixteen-inch brick wall.

Nearly all of the charges in this demolition were placed in holes cut to a depth of four inches, in a twenty-inch wall, which insured contact between the charge and the remaining thickness of the brickwork.

The following is an extract of the tabulated account of the details of the charges and explosions in the towers :—

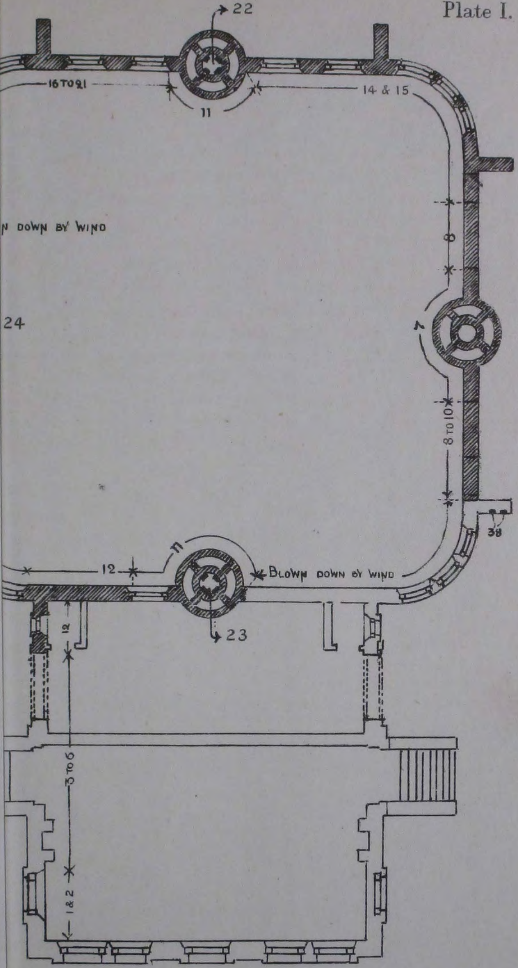
No. of Explosion.	No. of charge on Plan.	Explosive Used.	Weight of Charge.	Form of Explosive.	Remarks.	Position of Charge.	Firing Battery	Length of Leads.	Description of Circuit.	Test before Firing.	Account of Explosion and Results.
11	22	Guncotton.	lbs oz 37 4	Slabs $6\frac{1}{8} \times 6\frac{1}{8} \times 1\frac{3}{4}$ about $2\frac{1}{2}$ lbs. when dry.	The 37lbs. 4ozs. was divided up into 4 charges. The slabs for these charges were drawn from the Ordnance Store Department, wet. They were dried before being used. In each charge a single disc was used as a primer. A and B charges consisted of 4 slabs and 1 disc each. C and D charges consisted of 3 slabs and 1 disc. In each charge 2 detonators were used.	A B C D charges were placed inside the North Tower, on a shelf fixed on iron spikes (see *Fig.* 4, *Plate* IV.) The slabs and discs were lashed on to their pieces of board with spun yarn, to ensure close contract (see *Fig.* 9, *Plate* IV.)	40 cells of Leclanché Firing Battery capable of fusing platinum wire through a resistance of 20 ohms.	2 lengths of Hooper's core, each about 100 yards long, also some short lengths to connect the charges inside the Tower.	In Continuous Circuit.	Resistance of Circuit about 7 ohms.	The charges in the 3 towers were exploded at the same moment, and in an instant the towers disappeared. The explosion of the powder in the western tower made such a quantity of smoke that little could be seen actually of the fall of the towers. Total Fired :—Guncotton 74lbs. 8ozs. Gunpowder 100lbs.
	23	do.	do.	do.	The 4 charges in the Southern Tower—E and F charges had 3 slabs and 1 disc; G and H 4 slabs and 1 disc. (Arranged as shown in *Fig.* 5, *Plate* IV.)	These charges were fixed in the same way as those in the North Tower, and similarly placed; the larger charges being placed so as to take effect on the junction of the wall and tower (see *Fig.* 9, *Plate* IV.)	40 cells of Leclanché Firing Battery, capable of fusing wire through a resistance of 20 ohms.	do.	do.	do.	
	24	Gunpowder.	100 0	R.L.G.	The gunpowder was placed in a rectangular box; in order to ensure instantaneous ignition 6 electric gun tubes were laid in powder, so that the flash should pierce the entire mass at the same moment.	The box was suspended on 2 cross beams the ends of which rested in holes cut in the inner circle of brickwork (see *Fig.* 10, *Plate* IV.)	40 cells of Firing Leclanché capable of fusing wire through 20 ohms.	2 leads, each 80 yards long, with short lengths inside the box to connect the gun tubes	In continuous Circuit.	Resistance of Circuit about 8 ohms.	

It having been satisfactorily ascertained how much guncotton was required to destroy the towers, it was decided, as the safest method, to destroy the three remaining towers at one explosion.

The officer commanding the Artillery had offered 100lbs. of gunpowder to experiment with on one of the towers. The western tower, being the weakest, was the one selected. The gunpowder (R.L.G.) was put in a box resting on two cross pieces in the centre of the tower (see *Fig.* 10, *Plate* IV.), about six feet from the base. Six No. 10 low-tension electric gun tubes in continuous circuit were used to ignite this charge. The north and south towers were charged with 37lbs. 4ozs. of guncotton each and eight detonators.

To ignite the fuze and detonators in each tower, a battery of 40 Leclanché firing cells was employed. The three firing keys of the circuit were fixed on a piece of board, so that the three keys could be pressed by one hand at the same moment.

Plate I.



22
16 TO 21
14 & 15
11
N DOWN BY WIND
24
9
7
8 TO 10
38
11
12
BLOWN DOWN BY WIND
23
12
3 TO 6
1 & 2

PAPER V.

THE APPLICATION OF

INFANTRY FIRE IN THE FIELD.

BY CAPTAIN C. B. MAYNE, R.E.

The following paper is extracted chiefly from the first edition of a vork entitled *Infantry Fire-Tactics*, lately published by the writer;* nd in these pages only such matter as is universally agreed on s recorded, all contentious matter being eliminated.

In dealing with the application of infantry fire in the field, the eader is supposed to have a knowledge of the lectures given in the Musketry Regulations, while for technical matter and definitions the fficial *Treatise on Military Small Arms and Ammunition*, by Lieut.-Colonel H. Bond, R.A., must be referred to.

Before proceeding, we must define, with regard to their horiontal and vertical directions, the different kinds of fire which can e used.

Infantry fire, as regards its *horizontal direction* or *on plan*, is said o be:—

(1.) FRONTAL, when it is so delivered as to strike perpendicularly o the front of the object fired at.

(2.) OBLIQUE or CROSS, when the object is struck in front, but ot perpendicularly.

(3.) ENFILADE, when the direction of the fire is along the length f the object.

(4.) REVERSE, when the fire strikes the rear of the object.

* The first edition of this work is exhausted, and the writer regrets that for rious reasons he has not been able to bring the whole of the details of this per up to the additional information inserted in the second edition.

The moral effects of oblique, enfilade, and reverse fire are very much greater than those of a purely frontal fire, and therefore should always be used for preference when possible, but to do so necessitates the flank or rear of the enemy being gained; an oblique or cross fire can, however, in some cases be obtained by men firing rather towards one flank instead of to the front.

As regards material effect, the more oblique the fire is to the front the greater it is likely to be, as a greater depth of the object is struck or crossed by the fire, and hence enfilade fire has the greatest effect, independently of the moral effect it also has, by being delivered against the direct flank of the enemy.

Infantry fire, as regards *its vertical direction*, or rather *its trajectory*, is said to be :—

(1.) HORIZONTAL, when the line of sight is horizontal.

(2.) INCLINED, when the line of sight is inclined to the horizontal.

(3.) GRAZING, when the fire passes for some distance closer to the ground than the height of the object fired at.

(4.) DIRECT, when the fire is directed on a seen object.

(5.) PLUNGING, SEARCHING, CURVED, or DROPPING, when the fire is directed against an unseen object immediately behind a seen obstacle or cover, such as troops *close* behind an earthwork.

(6.) INDIRECT, when the fire is directed against an unseen object some distance in rear of a seen obstacle which covers it, such as troops in a valley *some distance* behind a hill.

It is easily seen from the above that any kind of fire, as regards horizontal direction, can be combined with any kind of fire as regards trajectory. Thus, a frontal fire may be horizontal, inclined, direct, plunging, or indirect, and so on.

Whether the fire be horizontal or inclined, the *trajectory for any given range remains practically in a constant position with reference to the line of sight.* So that having drawn the trajectory of a given range for a horizontal line of sight, we have only to move the whole figure up or down to obtain the trajectory for any given amount of inclined fire. This statement is not mathematically correct, though it is sufficiently nearly so for all practical purposes.

THE POWER OF THE MARTINI-HENRY RIFLE.

At target practice, men lying down, from being able to rest their elbows on the ground, fire more accurately than those kneeling; and those kneeling than those standing. Thus, the lying-down position should be the normal position for firing,* especially as the nearer the enemy is the more destructive is his fire, if he is not demoralized, and the more necessary is it to lie down in order to form the smallest possible mark ; this position has also other advantages besides that of allowing of more accurate shooting, viz., that the smoke of the powder in dispersing begins from the bottom, so that men lying down can see the enemy when men kneeling or standing up cannot distinguish anything through the smoke ; the lying-down position further allows of the smallest folds of ground being utilized as cover.

The following is an approximate *trajectory* table of the Martini-Henry rifle when it is held one foot above the ground, and aimed at the foot of the mark (see p. 84, *et seq.*). This supposes the man firing to be lying down, in which attitude he would almost always be in action—at long ranges to get a more steady aim, and at medium and short ranges to form a smaller mark. Hence, if aim is taken at the bottom of the objective, the line of sight may be taken as coincident with the ground. The height of cavalry is taken as eight feet, of infantry as $5\frac{1}{2}$ feet. The distances are given to the nearest yard, and the heights to the nearest $\frac{1}{4}$ of a foot, so that they are only approximations ; the ground is further supposed to be parallel to the line of sight. The data in this table are for a muzzle velocity of 1,320 feet per second, a fine day (*i.e.*, barometer 30 inches, thermometer 62° F., and the weight of a cubic foot of air 534·22 grains), and when the force of gravity $= 32\cdot1908$, and hence they would be different for other muzzle velocities, and other conditions of atmosphere and gravity.

* Of course, there are cases in which a lying down position would be useless, as in a flat country intersected with hedges, or when on ground covered with high grass, &c.

Table I.

1	2	3	4	5	6	7
Range in yards.	Angle of Elevation.		Greatest height of trajectory in feet above line of sight. (1)	Distance in yards of greatest height of trajectory from origin of fire. (1)	Angle of Drop.	
	Angle. (2)	1 in.			Angle. (2)	1 in.
	° ′				° ′	
0	...	...	...	...	...	...
100	0 10	381·67	0·25	52	0 12	304·00
200	0 21	163·31	1·00	105	0 27	128·00
300	0 34	101·11	2·75	160	0 44	78·20
400	0 49	70·17	5·00	216	1 2	55·40
500	1 9	49·82	8·50	273	1 22	41·90
600	1 27	39·51	13·25	331	1 45	33·00
700	1 46	32·42	19·00	387	2 11	26·10
800	2 6	27·27	26·25	446	2 42	21·20
900	2 28	23·21	35·25	507	3 15	17·60
1000	2 50	20·20	45·75	566	3 52	14·70
1100	3 14	17·70	57·43	623	4 34	12·50
1200	3 40	15·60	73·50	690	5 22	10·60
1300	4 8	13·83	90·50	752	6 15	9·13
1400	4 40	12·25	109·92	812	7 14	7·87
1500	5 15	10·88	...	...	8 20	6·82
1600	5 54	9·68	...	...	9 33	5·94
1700	6 37	8·62	...	...	10 53	5·20
1800	7 24	7·70	...	...	12 20	4·57
1900	8 14	6·91	...	...	13 56	4·03
2000	9 7	6·23	...	...	15 40	3·56
2100	10 3	5·64	...	...	17 44	3·12
2200	11 3	5·12	...	...	19 58	2·75
2300	12 7	4·66	..	...	22 21	2·43
2400	13 17	4·24	...	...	24 35	2·15
2500	14 25	3·89	...	...	27 50	1·89
2600	15 53	3·51	...	...	30 47	1·68
2700	17 28	3·18	...	...	33 35	1·50
2800	19 18	2·86	...	...	37 30	1·30
2900	21 10	2·58	...	...	41 30	1·13
3000	23 20	2·32	...	...	46 45	0·94

(1) These numbers suppose the line of sight coincident with the ground.
(2) These are given to the nearest minute of arc.

Table I. (Continued.)

8	9	10	11	12	13	14	15
Range in yards.	Theoretical dangerous space of mean trajectory in yards. (1)		Time of flight in seconds, over whole range. (1)	Striking velocity in feet per second. (1)	Maximum vertical error in feet.	Maximum horizontal error in feet.	Probable error in feet. (2)
	Cavalry.	Infantry.					
0	...	...	...	1320	...	...	...
100	Throughout	Throughout	0·24	1171	0·23	0·23	0·20
200	do.	do.	0·51	1051	0·40	0·35	0·30
300	do.	do.	0·81	982	0·69	0·58	0·47
400	do.	do.	1·12	927	1·08	0·86	0·74
500	163	92	1·46	880	1·33	1·07	0·94
600	92	63	1·80	838	1·68	1·38	1·18
700	70	48	2·15	805	2·10	1·68	1·46
800	56	39	2·51	773	2·58	1·98	1·77
900	47	32	2·88	741	3·16	2·35	2·12
1000	39	27	3·32	711	3·85	2·78	2·60
1100	33	23	3·76	681	4·68	3·20	3·12
1200	28	19	4·23	657	...	...	...
1300	24	17	4·68	635	...	...	...
1400	21	14	5·15	614	...	...	...
1500	18	12	5·65	595	...	...	...
1600	16	11	6·19	576	...	...	...
1700	14	9·5	6·75	560	...	...	...
1800	12	8·5	7·31	545	...	...	...
1900	11	7·5	7.89	530	...	...	...
2000	9	6·5	8·50	517	...	...	...
2100	8	5·5	9·13	505	...	...	...
2200	7	5	9·93	495	...	...	...
2300	6	4·5	10·77	487	..	...	...
2400	5·5	4	11·64	482	...	...	...
2500	5	3·5	12·56	479	...	...	...
2600	4·5	3	13·71	475	...	...	...
2700	4	2·7	14·94	476	...	...	...
2800	3·5	2·5	16·26	479	...	...	...
2900	3	2	17·65	486	...	...	...
3000	2·5	1·7	19·31	504	...	...	...

(1) These numbers suppose the line of sight coincident with the ground.
(2) The probable error is the radius of the circle containing the best half of the hits on a vertical target.

The five qualities of a military rifle, in order of relative importance, are as follows, the 1st, 2nd, 3rd, and 5th being known as the *ballistic* qualities of the rifle, and form a guide as to what can be expected from it in the field.

1. Long Range; but the range alone is not sufficient to give an exact measure of the ballistic value of the arm, and hence :—
2. Flatness of Trajectory must be considered as well. It should be as flat as possible to make a low trajectory, and therefore to increase the dangerous space, and to diminish the effect of any errors made in the estimation of the distance.
3. Accuracy of Fire is the greater or less probability of striking the object aimed at. We shall deal with this more at length later on, when we shall see why the quality of accuracy is placed third on the list; but with equally flat trajectories, the more accurate the weapon the greater value it has in war.
4. Rapidity of Fire, or the number of shots which can be fired in a given time, governs the *intensity* of the fire, and, as we shall see further on, may make a moderately accurate fire more effective and terrible than a more accurate and slower one. The rapidity of fire *permissible* is, however, governed to a great extent by the facility of loading and by the amount of ammunition available; as we shall see hereafter, the greatest *possible* rapidity of fire is never required.
5. Penetration, or the power of damaging the object when struck. If the projectile fails in penetrative power, all the above qualities are useless. But as all the present military rifles possess this quality sufficiently for all practical purposes, it will not be dealt with again.

For a given range the trajectory is flatter, as the ordinates and the angles of elevation and descent are smaller. Flatness of trajectory is perhaps the principle quality of an arm for war, for on it depends the dangerous zones as well as the power of ricochets.

Very accurate weapons with high trajectories are all very well with skilful and cool men, and who know their distances exactly; but great accuracy of fire cannot at any time be readily utilized by the mass of men, especially when excited under fire and unsteady from rapid movement. The errors of a good shot firing without a rest are double those made when firing from a rest; for an average shot they vary from three to four times more; while those of a bad shot, who fires hurriedly and without aiming, are incalculable. But flatness of trajectory can be utilized immediately by every man, both good and bad, as it is independent of the man, and thus a flat trajectory increases the value of a rifle for military purposes.

Hence we should principally aim at progress in flattening the trajectory of the arm more than increasing its accuracy.

We must always remember, however, that *rifles are weapons whose value only depends on the skill of those using them.*

Ricochets.

As a rule, in experiments against targets we do not deal with the effect of "ricochets," but to do so in the field is to detract, to a very important extent, from the full value of our fire. The following remarks on the value of richochets have been extracted from the report of the Siege Operations Committee on the fire of the Martini-Henry rifle.

If the angle of drop is not too great, and the nature of the ground suitable, a bullet on striking the ground will glance or ricochet off it and go on, but on account of the right-handed twist or rotation of the bullet, given by the rifling of the barrel, the bullet usually deflects to the right after touching the ground. Experiments have shown that *the mean rise of the ricochets, after touching the ground, is about twice the drop*, but it is very variable, and the mean deflection to the right is about 1 in 100, the maximum being 2 in 100, so that it may be taken as almost continuing in the plane of the trajectory.

The practical limit in range on level ground at which ricochet can occur is about 2,000 yards where the drop is 1 in 3·56, but it depends greatly on the nature and slope of the surface on which the bullets fall (see page 120).

Individual Fire.—Its Inaccuracy.

By *individual fire* is meant an independent fire in which each rifle is directed on a different object, the range and elevation being either judged by the soldier himself or given him personally by his leaders.

Experiment shows, and theory, as we shall see, confirms it, that however good a shot a man may be, his bullets will never strike on the same spot, even when the same point is aimed at each time with the same elevation, but they will fall over a considerable *area*, whose length in the direction of the fire is much greater than the breadth at right angles to it. This can only be due to involuntary "errors" being made both in elevation and direction at the instant of firing; and from the elon ated space over which the bullets strike, we conclude that, in shooting, any errors made in elevation tell more than the same errors made sideways or in direction. These errors arise from a variety of causes, and they show more and more as the number of men firing increases, because it is quite improbable that each man will bring his rifle to the shoulder, aim, and pull the trigger in the same way, or have adjusted his back sight to exactly the same height by such insensitive means (though the only ones possible in the field) as his forefinger and thumb, or to have used the same amount of foresight in aiming as the others.

The causes of irregularity, or of errors, in the firing of a rifle, may be classified under seven different headings, some of which apply both to firing in the field and at targets on measured ranges, and others only to the latter case. The causes of error are as follows:—

1. Imperfect means of ascertaining the exact range.
2. Imperfections in the soldier.
3. Imperfections in the rifle.
4. Imperfections in the ammunition.
5. Adverse atmospheric conditions.
6. The method of executing the fire.
7. The duration of the fire.

Most of these causes may be further sub-divided into *constant* and *variable* causes. The constant causes of error deflect the fire without necessarily altering the accuracy of it, that is, they will produce a "concentration" or "good grouping" of hits, but off the point aimed at, and they only require the soldier to make suitable corrections in aiming to place his shots around the point to be hit. The variable causes of error are those which vary with each shot and produce a "dispersion" or "bad grouping" of hits; they are as a rule due to the bad or irregular manufacture or preservation of the ammunition, to the want of skill in the firer, to adverse or inconstant atmospheric conditions (such as gusts of wind, great cold which numbs the soldier, cloudy weather, an obscure or badly lit-up mark, etc., which render accurate aiming impossible), and to other accidental or temporary causes, such as a heated barrel which burns the hands, the trembling caused by fatigue or long continuous firing, etc.

To enter fully into the above seven causes of error would take up far more space than is available, and the writer has dealt with them elsewhere. But one point is very essential to realise, viz., the effect of using a full foresight with the Martini-Henry rifle, which is graduated for a fine foresight.

A fine foresight is all very well for match firing, but in the excitement of action, when men are fatigued with marching, breathless with rapid moving, or when firing at objects which are only seen for a few moments, it is impossible, even if the men aim at all, to use a fine foresight, and hence a full foresight is invariably made use of, which causes the fire of the Martini-Henry rifle to go high. The height of the foresight is 0·12 inches, and its distance from the backsight, when the latter is down, is 24·55 inches, and when the backsight is up, 26·50 inches; hence when the backsight is down the foresight subtends an angle of 16·80 minutes of arc, and when the backsight is up, an angle of 15·58 minutes of arc. Hence, if we suppose an error of 15 minutes of elevation to be caused by the use of what is known as "a full foresight," we find that, at the different ranges given below, it would cause the bullet to strike the number of feet, given in the following table, higher than it should at the different distances stated from the muzzle of the rifle.

Table II.

Range in Yards.	Approximate rise of the bullet in feet, due to using a full foresight, equivalent to 15 m. of arc, with the Martini-Henry rifle.							
	At 100 yds.	At 200 yds.	At 300 yds.	At 400 yds.	At 500 yds	At 600 yds.	At 700 yds.	At 800 yds.
100	1·47	—	—	—	—	—	—	—
200	1·34	2·87	—	—	—	—	—	—
300	1·23	2·61	4·12	—	—	—	—	—
400	1·00	2·07	3·27	4·55	—	—	—	—
500	1·17	2·50	3·93	5·47	7·08	—	—	—
600	1·16	2·49	3·92	5·44	7·06	8·80	—	—
700	1·14	2·45	3·86	5·36	6·95	8·67	10·45	—
800	1·09	2·32	3·65	5·07	6·56	8·19	9·89	11·65

REMARK.—This table also shows the effect of using too much foresight with the Martini-Henry rifle. If one-tenth of the foresight was used, instead of a fine sight, the error would be about one-tenth of the above figures.

Thus we see that the use of a full foresight with the Martini-Henry rifle makes a difference of about half the height of a man at 250 yards, and the whole height of a man at 450 yards, showing the necessity of graduating the backsight for a full foresight, such as the men would use in the field. *A fine foresight is quite inapplicable for war purposes.*

Another point that must be referred to is the very excessive recoil of the Martini-Henry rifle; it amounts to 16·6 foot lbs., or 3·5 foot lbs. greater than that of the French rifle, and 5·5 foot lbs. greater than that of the German and Russian rifles. Few men can fire 70 rounds consecutively fairly from the shoulder with our rifle, and the pain caused by the recoil only tends to cause a deplorable waste of ammunition on the battle-field by inducing men to fire without bringing the rifle to the shoulder, and therefore without aiming.

DETERMINATION OF THE ACCURACY OF A RIFLE.—DIMENSIONS OF THE SHOT-GROUPINGS OF A MARTINI-HENRY RIFLE FOR INDIVIDUAL FIRE.

From what has been said, we see that, however great care may be taken to render all the conditions of fire identical, we can never obtain the same trajectory for even similar projectiles fired under apparently the same circumstances, and that the influences acting on the fire of a rifle are so diverse, that if the same soldier fires a series of about 50 bullets at least with the same rifle, without committing the least personal error, and while constantly aiming at the same point, these projectiles will cover, when received on a target, a more or less great *surface* or *area* called *the grouping of the shots.** If the shots are received on a vertical target, the surface covered with hits is called *the vertical grouping of the shots (Fig. 1)*; and if the bullets are

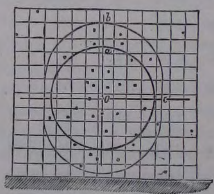


Fig. 1.

The vertical grouping of a series of shots.

o a Radius of the circle enclosing the best half of the hits ....
o b Radius of the circle enclosing all vertical deviations .. ..
o c Radius of the circle enclosing all horizontal deviations ....

} Some abnormal hits not included.

* This shows the uselessness of a soldier at target practice altering his sight after *each* round, because the particular shot does not strike the *exact* point aimed at.

allowed to pass on and to fall on a horizontal surface, or one sensibly parallel to the line of sight, *the* grouping of hits is called the *horizontal beaten surface*, or the *horizontal grouping of the shots (Fig.* 2). The groupings of the shots are usually formed on a vertical target for individual fire, and on a horizontal surface for collective fire.* The general form of the grouping will be an ellipse in each case, but on a horizontal surface its major axis will be much longer both absolutely and proportionately to its minor axis.

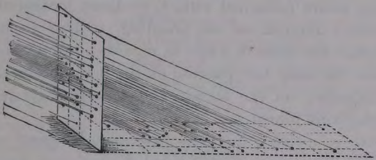


Fig. 2.

The horizontal grouping of a series of shots.

The hits forming these groupings are closer together towards the centre, where a *nucleus* is formed, while towards the edges they are further apart.

Taking all the different hits on a vertical target, we see that every bullet which does not strike the point aimed at has, with respect to this point, an *error in height* and an *error in direction.*

There results from the above, that we cannot fire along an isolated trajectory, and as there is no reason why the causes, which influence the flight of a projectile, should not act as much in one direction as in another, when a large number of shots are fired, the deviations occur in all directions, and we now require to find the curve which occupies a mean position among all the trajectories described by the bullets fired. This curve is called the *mean trajectory*, and is that which each projectile would follow if the causes which modified its movement had not existed. The differences between the real and the mean trajectories are called the *errors* of the projectile, these errors being due to the causes already enumerated.

If we conceive the range divided into a certain number of parts, then the ordinates of the mean trajectory, at the points of division, will be the mean of all the ordinates of the trajectories of the bullets fired, at the same points of division.

* By *collective fire* is meant a fire delivered from several rifles and directed on the same object.

This mean trajectory is the one that all calculations and data are usually referred to, and it is the trajectory worked out by Bashforth's Tables. Table I. on pp. 84 and 85, refers only to the mean trajectories of the different ranges.

The point where any bullet strikes a vertical or horizontal target is called its *point of impact*, and the point where the mean trajectory would strike the same target *(i.e.*, the central point of the group of hits), is called the *point of mean impact.*

The above errors (obtained either by direct measurement on the target, or from a diagram of the shooting, plotted to scale) permit us to appreciate the value of a fire, as regards accuracy alone. From them we can calculate the position of the point of mean impact of the mean trajectory on the target, and therefore its position with respect to the point aimed at.

The accuracy of a rifle at any given range may be defined as the probability it gives of striking an object of given dimensions at that range. It depends both on the position of the point of mean impact with regard to the point aimed at, and of the manner in which the shots are grouped around this point of mean impact.

The value of a rifle is greater for a given distance, according as the point of mean impact of the shots fired at this distance is nearer to the point aimed at, and as the shots are more concentrated round the point of mean impact.

Now because the manner in which a rifle groups its shots is the measure of its accuracy, it is very necessary in determining the accuracy of a rifle, to eliminate the effect of the accidental causes which make the projectile deviate from the point aimed at, and therefore for this purpose we take *the mean absolute error with respect to the centre of the group* round which all the shots are distributed.

The *mean absolute error* for any range with reference to the point of mean impact, is called in England the "figure of merit" for the given range, and it is the method of comparison used in England for the fire of different rifles. The actual horizontal and vertical errors are not considered in the English service in estimating the comparative accuracy of two or more rifles, though, as we shall see, they have the highest importance in considering the question of individual fire in the field, and experiments to ascertain them are urgently required.

A term, called the *probable error*, is often made use of, and it means the radius of the circle drawn round the point of mean impact as a centre, which contains the inner or best half of the hits. To find it, place all the absolute errors, with respect to the point of mean impact, in their numerical order; then, if there are n of these errors, the $\frac{n}{2}$th number, if n is even, or the $\frac{n+1}{2}$th number, if n is odd, is the probable error.

Table III., p. 94, gives, in column 2, the *approximate* values of the probable errors of the English rifle for ranges varying from 100 to 1,100 yards. They are taken from the report of the French Committee, who made experiments at Vincennes with different European rifles. The rifles were fired from the shoulder by a good shot, who made use of a rest for his elbows only. The French Committee gave the errors for every 100 mètres (110 yards), and the value for the ranges stated have been determined by means of a graphical curve of probable errors (see *Fig.* 3, p. 95).

The two columns, 3 and 4, giving the *radii* of the circles which enclose *all* the vertical and *all* the horizontal errors, have been calculated (for want of practical information regarding them) proportionally to the probable error from similar statistics given in the German Musketry Regulations for the Mauser rifle.* This method of doing so is not mathematically correct, but it is sufficiently near the truth for comparative work; the necessary data have not been obtainable for getting a more accurate result, and it is hoped that experiments will be made in England to obtain these valuable and necessary statistics.

In no German, or other work, has it been found why the percentages given in column 5 of Table III., are deducted from the recorded hits before determining the values of the errors, but doubtless the necessity for doing so has been found from the immense number of experiments which the Germans have made.

* These statistics have been found with the use of "full" sight. In England a fine sight is used because the backsight is graduated for it.

Table III.

DIMENSIONS OF THE SHOT-GROUPS MADE BY THE MARTINI-HENRY RIFLE ON A VERTICAL TARGET.

1	2	3	4	5	6
Range, in yards.	Probable error, or radius enclosing the inner 50 per cent. of hits.	Radius of circle enclosing all the vertical errors.	Radius of circle enclosing all the horizontal errors.	Percentage of abnormal hits deducted from those recorded.	REMARKS ON DOUBLE THE HORIZONTAL AND VERTICAL ERRORS.
Yards.	Feet.	Feet.	Feet.		
50	0·10	0·11	0·11	0	
100	0·20	0·23	0·23	1	
150	0·24	0·29	0·29	2	
200	0·30	0·40	0·35	3	The size of a head.
250	0·37	0·52	0·44	4	
300	0·47	0·69	0·58	5	A little less than the width of the vunerable part of a man.
350	0·59	0·85	0·72	5	
400	0·74	1·08	0·86	6	
450	0·83	1·17	0·94	7	A little more than the width of a man.
500	0·94	1·33	1·07	8	
550	1·05	1·50	1·20	8	
600	1·18	1·68	1·38	9	
650	1·31	1·87	1·51	10	A little more than the height of a kneeling man.
700	1·46	2·10	1·68	10	A little less than the width of two men.
750	1·61	2·30	1·81	10	
800	1·77	2·58	1·98	11	
850	1·94	2·84	2·14	11	Rather greater than the height of a man.
900	2·12	3·16	2·35	11	
950	2·39	3·57	2·60	12	
1000	2·60	3·85	2·78	12	
1050	2·85	4·37	2·99	13	
1100	3·12	4·68	3·20	13	

GRAPHICAL CURVE OF THE ERRORS GIVEN IN TABLE III.*

The above errors are those made by a good marksman, and it must be clearly remembered that *these numbers are by no means absolute, but only comparative.* The accuracy of the fire varies every day, as the ammunition and as the density of the air and consequently the

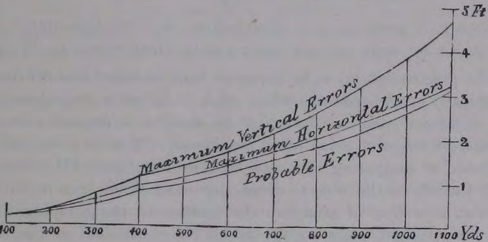


Fig. 3.

retardation varies, and according to the condition, eyesight, and skill of the firer. But the above numbers furnish a useful basis for comparison, and for working on.

PRACTICAL TRAJECTORIES AND THE EMPLOYMENT OF PARTICULAR SIGHTS TO CERTAIN RANGES AND OBJECTIVES.

Before the Franco-German war of 1870-71, the universal idea was, that the individual skill of an average shot with his rifle was the measure of the efficacy of the fire of the masses. As, at that time, the maximum distance for firing was considered to be 450 yards, this idea was quite true, but after the war, when *the fire of the masses* had been found to be effective at ranges far beyond those of effective individual fire, a complete revolution took place in the German Army as to the method of using rifle fire in the field,

* In results obtained by the Martini-Henry rifle, there seems to be some kind of anomaly between the results obtained up to 400 yards and those for ranges beyond this. This is due to the different methods of sighting used, and the alteration of the distance of the backsight from the eye for ranges under and over 400 yards. This fact is also very plain in Table II. p. 89.

Table III. shows the folly of altering the elevation, as is often done, after each shot because it does not hit the exact spot aimed at. If the shots hit within the limit of error, that is all that can be expected. The elevation should only be altered when the successive hits indicate the fire is too high or too low generally.

and which has since 1877 (when the system was first made public) been adopted *in toto* by every European power but ourselves.

The following pages, adapted to suit the Martini-Henry rifle, give the principles on which the German musketry regulations, and those of other Continental powers, entirely rest. Their perfection will be seen by the solid basis on which they are founded.

Connection between the Dimensions of Shot Groupings and those of some of the most usual Objectives in War.

The practical effects to be expected from an individual fire depend principally *on the connection which exists at the given range between the size of the shot group and the size of the object to be hit, and also on the position of this shot group above the ground.* Thus we see the importance of comparing the data contained in Table III., on p. 94, with the size of the objects which are most often seen in the field in war, as well as of studying the position of the groupings above the line of sight when we fire at an object situated at the range exactly corresponding to the elevation used, and also at ranges which do not correspond to this elevation. This latter point is a most important one, as ranges are never exactly known in the field.

The following dimensions* may be accepted as the average height and width of the most usual objectives met with in war.

	Feet.
The height of a man standing	5·50
,, ,, ,, ,, running forward	5·33
,, ,, ,, ,, kneeling	3·67
,, ,, ,, ,, lying down in the open	1·50
,, ,, ,, ,, lying down under cover	1·17
,, ,, ,, a mounted man standing still	8·00
,, ,, ,, ,, ,, riding at a rapid pace	6·67
Total width of a man	1·75
Width of the vulnerable part of a man	1·33
,, ,, a group of 2 men in close order	3·56
,, ,, ,, 3 ,, ,,	5·25
,, ,, a horse and rider	3·00

If the group of shots is well placed, the bullets will always strike the object so long as the shot group has either a smaller, or the same extent, of surface as the object, but when that distance is reached where the shot group has a larger surface than the objective, then many of the bullets, *though well directed*, will miss the mark

* These are the usual dimensions accepted abroad.

without any fault of the firer, and an uncertain fire is the result. The proportion of misses increases in proportion as the extent of the shot group exceeds that of the objective. Thus, in order to put 97 per cent. of the shots fired into an object at 200 yards, it must be at least 0·7 feet wide and 0·8 feet high (see Table III.), always supposing the group is well placed.

The position of a shot group is determined by that of the centre of its figure, that is to say, of its point of mean impact.

The ordinates of the mean trajectory (which passes through the centre of the shot group) express the distances of the centres of the shot groups from the line of sight. The table in Appendix I. gives the ordinates above the line of sight of the mean trajectories, or centres of the shot groups of the Martini-Henry rifle for different ranges 100 yards apart, for every 50 yards.

When a large number of shots have been fired, the mean trajectory of these occupies a mean position passing through the point of mean impact, and is the theoretical trajectory of the whole. We will suppose that it passes through the spot aimed at on the object to be hit. The ellipse drawn round this point, with diameters equal to twice the greatest vertical and horizontal errors respectively for the range, will include all the hits, less the deduction made for abnormal shots.

As we go from 100 yards to 200, 300, 400 yards, etc., we find that the ellipses increase with the distance, but in a more rapid ratio. Now practically for rifles, every trajectory includes in itself the trajectories of the lower ranges. This is known as *the principle of the rigidity of the trajectory*, the error caused by this supposition being inappreciable. Hence, if we trace the mean trajectory for some long range, say for 1,000 yards, and draw the ellipses at each range with their centres lying in the mean trajectory, and join

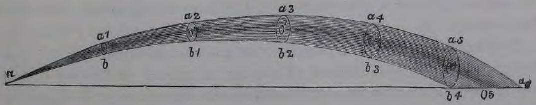


Fig. 4.

$a\ a_1$ .... a_6	Upper Trajectory.	
ao .... o_5	Mean	,,
ab .... b_4	Lower	,,

their circumferences, we obtain a "bundle" of trajectories, which form a kind of curved cone, which is very small in section at the shortest distances, and goes on enlarging at the greater ones, just like a jet of water from a fire engine.

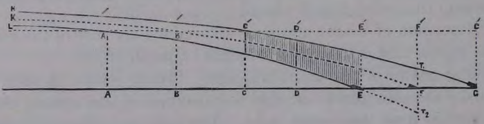


Fig 5.

HC'G Upper Trajectory.
LA'E Lower ,,
KB'F Mean ,,
The line A'B'C' . . . G' is at the height of the objective above the ground line ABC . . . G.
AG = Total dangerous zone, exclusive of ricochets.
AE = Grazed zone.
AC = Rear part of dangerous zone.
CE = Central part of dangerous zone, or zone grazed by the whole cone.
EG = Front part of dangerous zone, or beaten zone.
D is the central point of the zone CE.

The position of the shot groups with respect to the line of sight, and the relative areas of these groups at the different distances, show that the trajectories of a series of shots form an imaginary solid, like a curved cone, of an elliptical section, of which the apex is at the muzzle of the rifle, and which opens out according as the distance of the firer from the target increases. This imaginary curved cone is called *the cone of dispersion of the shots*, and the curve which forms the axis of this cone is what we have called the mean trajectory; the shot groups are the sections made in the cone by vertical surfaces, whilst the beaten ground is determined by the intersection of the cone with the ground.

The knowledge at each range of the maximum errors allows us to judge accurately the chances of hitting an object of known dimensions, while the theoretical or mean trajectories are only of theoretical value to us in calculating the mean height of the bullets above the line of sight in their flight for different ranges, and therefore for practical purposes we must use instead of them the *practical trajectories*, which may be defined as the mean trajectories surrounded by the cone of dispersion, containing all the remaining trajectories.

The general form of the cone of shots is usually expressed by its extreme (upper and lower) and mean trajectories; and the cone of shots is generally graphically shown by drawing these three lines, as in the foregoing figures.

The ordinates of the extreme trajectories can be deduced from that of the mean trajectory, because twice the greatest vertical errors of the groups (given in Table III.) show the distance separating the extreme trajectories of the cone, and they are divided into two equal parts by the mean trajectory. Thus, to determine the value of the ordinate of the upper trajectory of the cone for any given distance, we must add to the corresponding ordinate of the mean trajectory at that distance, the greatest vertical error of the shot group at the distance at which the ordinate cuts the trajectory. The ordinates of the lower trajectory are similarly found by the subtraction of the greatest vertical error from the ordinate of the mean trajectory.

Before proceeding further we must first consider the requirements of a battle-field.

"In a battle which is intended to be brought to an issue, one side must act on the offensive, the other on the defensive; the *rôles* may be interchanged, but at any given moment the opposing front lines of the adversaries must be either advancing to the attack, or staying still to defend the position attacked; therefore the distance between the two sides tends to diminish, and it becomes most important that that the intervening space between the adversaries should be swept by a storm of bullets. *The ideal of rifle fire in the field is reached when no bullet in the intervening space between the opponents passes over the head of a standing man; that is, does not rise higher than 5 feet 6 inches above the ground.*

"Other kinds of actions there are: demonstrative, and retreating; in the former a delaying fire is made use of, and time is given to work out distances; in the latter, the victors being safe, have to raise their sights as the enemy flies before them. But before the action is decided, when the strain is most intense and time most limited, then the fingers must hold the rifle firmly, as it may at any moment be required for use with the bayonet; they cannot be loosened to fiddle with a sight, or to adjust it to distances of 50 yards, nor can the eyes be lowered for the purpose, or taken off the enemy, when he is advancing on us, or we on him." Moreover, at close ranges under 400 yards, the men are too excited to think of altering their sights. It is no good saying "They must," for all experience shows they will not do so.* The moral excitement of the fight at close ranges is too great to expect the power of control to be kept up with regard to details, though discipline may still allow the men to be carried forward and attend to the larger questions. For battle requirements, therefore, a single elevation for 400 yards at least is required, which must be made capable of use at shorter ranges by the flatness of the trajectory. How this is to be done will be presently shown.

The object in war is to put the enemy out of action; the object sought for must be considered as attained if the enemy is struck anywhere. This is a most important principle to recognise and bear in mind, for it is one of the foundations on which the following pages rest.

In discussing the question of rifle fire in the intervening space between closely opposing forces, tables based on the employment of the 400 yards sight will alone be made use of; for if they serve to prove that it is advantageous under the above circumstances to aim at a certain portion of the objective with this sight, then analogous tables based on the use of other sights are not needed, as they would only tend to confirm the same fact.

The shot groups of an individual fire have hitherto only been considered with reference to an object situated at the exact distance corresponding to the elevation made use of; they must now, however, be further considered with reference to an object which is situated at a less distance than that of the elevation employed, aim always being taken at some point on the objective.

Suppose we are using the elevation for 400 yards, and aiming *at the bottom* of an objective (5·50 ft. high) placed at 350 yards from the rifle, then the centre of the group will be placed at 2·14 feet (the ordinate at 350 yards for the trajectory of 400 yards) above the line of sight, that is to say from the ground when aim is taken at the bottom of the object.† If in the same conditions we aim at the centre of the object (at 2·75 feet above the ground), then the centre of the group will be placed at (2·14 + 2·75) or 4·89 feet above the ground.

The position of the centres of the shot groups is thus given, when aim is taken at the bottom of the object, by the ordinates of the

* "At the short distances, the rapid firing ought to be executed with a constant elevation, because the men cannot be got to modify their sights when they are wildly excited by the fight, and are, so to say, in the middle of fire." —(General Brialmont.)

† The effect of always aiming at the feet of an enemy is the same as if the latter walked up the line of sight.

mean trajectory, and when aim is taken at the centre of the object, by these ordinates increased by half the height of the object. Hence, this position varies according to the height of the point aimed at, while it is entirely independent of the height of the point of the origin of the fire—*i.e.*, the position taken by the firer. But this position has some effect on the dangerous zones produced; the kneeling position was at 400 yards a dangerous zone 50 yards longer than that for the standing position, when aim is taken at the foot of the object.

Table IV. gives the heights above the ground of the extreme upper and lower trajectories of the cone for 400 yards, on the supposition that aim is taken with the 400 yards elevation at the bottom and at the middle of an object 5·50 feet in height, placed successively at 400, 350, 300, 250, 200, 150, 100, and 50 yards from the muzzle of the rifle.

The heights of the extreme trajectories are deduced as already stated, from those of the centres of the groups by the addition or subtraction of the greatest vertical errors of the groups.

Table IV.

HEIGHTS OF THE EXTREME TRAJECTORIES ABOVE THE GROUND, SUPPOSED TO BE PARALLEL TO THE LINE OF SIGHT, WHEN AIM IS TAKEN IN ANY POSITION OF THE FIRER, WITH 400 YARDS SIGHT, AT THE FOOT OR CENTRE OF AN OBJECT, $5\frac{1}{2}$ FEET HIGH, PLACED SUCCESSIVELY AT THE DISTANCES GIVEN BELOW.

Distances.	Upper Trajectory.		Lower Trajectory.	
	Bottom of object.	Centre of object.	Bottom of object.	Centre of object.
Yards.	Feet.	Feet.	Feet.	Feet.
50	2·01	4·76	1·79	4·54
100	3·68	6·43	3·22	5·97
150	4·83	7·58	4·25	7·00
200	5·47	8·22	4·67	7·42
250	5·48	8·23	4·44	7·19
300	4·81	7·56	3·43	6·18
350	2·99	5·74	1·29	4·04
400	1·08	3·83	1·08	1·67

As has been said, the object to be attained, in order to insure a decisive fire fight at close ranges, is that no bullet in the intervening space should pass over the head of a standing man, and hence it is only necessary to deal with the upper trajectories of the cone of bullets. From the above Table IV., we see that the 400 yards range is the greatest range at which the upper trajectory of the Martini-Henry rifle always keeps within the height of a standing man, and then only when aim is taken at his feet, and hence the following deduction is at once made from this table, that *when the rifle is directed at the bottom of an object, the intervening space is better swept by the cone of bullets than if it was directed at the centre of the object.*

In dealing with the Martini-Henry rifle we must not forget that its backsight is graduated for use with a *fine* foresight. But in action men will use a *full* foresight, and if the 400 yards elevation is used in action, even if aim is taken at the foot of an advancing enemy, we must add the errors given in Table II. (p. 9), for the 400 yards range to the above numbers in Table IV., which shows that the bullets would fly well over the heads of the enemy from 150 yards and onwards. This is probably the cause of the bad shooting in the field of our troops that we have heard so many complaints of. To use the Martini-Henry rifle in the Continental manner for close fighting under 400 yards, it would be necessary to use the 300 yards elevation and let the men use a full foresight. If we add the errors made by using a full foresight with the 300 yards elevation (given in Table II.) to the numbers given in Table V. (a similar table to Table IV., but for the 300 yards range), we will find that the results are very satisfactory for obtaining a very efficacious fire for battle purposes at short ranges, *provided aim be taken at the bottom of the objective.*

Table V.

Distances.	Upper Trajectory.		Lower Trajectory.	
	Bottom of Object.	Centre of Object.	Bottom of Object.	Centre of Object.
Yards.	Feet.	Feet.	Feet.	Feet.
50	1·42	4·09	1·20	2·87
100	2·45	5·12	1·99	4·66
150	2·92	5·59	2·34	5·01
200	2·86	5·53	2·06	4·73
250	2·11	4·78	1·07	3·74
300	0·69	3·36	0·69	1·98

From this table we see that if the aim be directed on the foot of the object, the upper trajectory is everywhere under the height of an object equal to half the height of a man (or 3·67 feet), as its greatest height is 2·92 feet. Hence, for the Martini-Henry rifle, all that is actually required for war purposes as regards sights for short ranges, when aim is taken at the foot of the object, is a fixed sight for 300 yards, and a flap sight for 400 yards, and the usual leaf sight for longer ranges; but the backsight ought to be graduated for a full foresight which men will always use in action.

Tables IV. and V. will enable us to see why, if we follow, like other nations have, German ideas, we should be justified—

(A) In adopting the bottom of the object as the normal point to be aimed at.

(B) In limiting the number of elevations to be used, and their employment to certain ranges and objectives.

Aim in action always should be directed at the foot of the object, for the following reasons:—

(*a*) That the intervening space swept by the cone of bullets is lengthened.

(*b*) That the evil arising from the use of a fuller sight than the backsight is graduated for is mitigated.

(*c*) That the ricochets of the lower half of the cones of dispersion are better utilized.

(*d*) That tactically it is advantageous. (See p. 55).

Limits for the Employment of Individual Fire.

Individual fire is the fire of individual men when left to their own initiative, that is to say it is the fire of men freed from all control, and therefore free to choose their object, their elevation, and to regulate their own consumption of ammunition, while *collective fire* is the regulated, if not simultaneous, action of a number of rifles against the same objective in obedience to the wish of a single man. In the first case, the fire is left to the initiative of the individual men, whence its name of individual fire, and in the second case, it is placed in the hands of a leader.

Now it is very important to remember that there are two completely different conditions under which individual fire can be used:

1. Against a mass of enemies in a battle, and
2. Against a single enemy, or a small group of men when accidentally met with.

With this second condition only it is intended to deal with here at present. For want of recognition of these two cases, much misunderstanding has arisen in defining the limiting ranges of individual fire, when directed against objectives of various sizes, for the soldier would naturally say, "If it is laid down that I am not to fire at a kneeling man, say beyond 300 yards, then I must never do so if he is at ranges beyond that." On the face of it we see that such a conclusion would be absurd for battle requirements, where circumstances are quite different to the second case given above. In action, in front of the soldier there is a practically continuous line of enemies, behind which, at various intervals, come other lines and other bodies of men. If he fires at a particular man in the front line, whatever his attitude (though usually it is only a bank of smoke a soldier has to aim at), and if he misses the particular man aimed at he may hit another at either side of him, or one in the lines or bodies of troops behind, while the noise of his firing cheers himself while that of his passing shot tends to instil fear into the enemy.

Hence in action the following rules for the limits of individual fire cannot apply in the full. On p. 80, *et. seq.*, we will more thoroughly study the question of fire tactics in battle. At present we must remember that we are not dealing with such tactics.

Accepting the above definition of individual fire, it becomes necessary to fix some limits within which this fire may be employed, or else a serious waste of ammunition would take place from the area of the shot groups being too large as compared with that of the objective fired at. The accuracy and flatness of trajectory of a rifle, the skilfulness of the men in firing, and the errors made in judging distances, lay down precise limits for the employment of individual fire under the supposed conditions.

These limits may be theoretical or practical; the first case supposes a very good shot making no mistakes and knowing the exact distance; the second assumes that the two factors of errors in aiming and errors in estimating distances, will always militate in the field against attaining the theoretical result.

First, with regard to the *theoretical* limit for the employment of individual fire in the field, leaving out of consideration any want of skill of the firer, let us see what the limit for the use of individual fire should be when the range and elevation for it are exactly known. In this case the centre of the shot groups coincides with the position of the objective, and hence the *depth of the ground grazed by the whole cone* does not affect the question *provided such a zone* *exists.* In *Plate* I. we see that 800 yards is the maximum range at which there is such a zone grazed on the whole cone. Further, at 800 yards, the depth of the shot group being 5·16 feet (see Table IV.) or nearly the height of a man, and its width 3·96 feet, a good firer will put 89 per cent. of his shots *in an objective of a group of 3 men*, but beyond 800 yards the depth of the groups are more than 5·50 feet, and even a good firer cannot put a definite proportion of his shots into a line of infantry ; he only fires by chance and trusts to luck.

Now, with regard to the *practical* limit for the employment of individual fire in the field. As said above, two factors govern it : errors in aiming, and errors in judging distance.

From numerous experiments made in Germany it has been found that the average errors made in judging distances up to 1,200 yards is from $\frac{1}{6}$th to $\frac{1}{7}$th the estimated distance. The Russians say $\frac{1}{10}$th the range is the average error. The German rules for firing however, allow for an error of $\frac{1}{8}$th the range which will be the error used throughout this book. For ranges less than that at which the trajectory is under the height of a man (viz., under 400 yards), this single error is used ; for greater ranges the error may be under as well as over the true distances, and consequently the double error must be used.

At 500 yards the width of the shot group is only about 2·14 feet, and its depth is 2·66 feet. Thus, at this distance, a *good shot using the proper elevation*, and firing on a group of two men (3·50 feet wide) will put 92 p.c. (deducting abnormal shots) into the objective. But this good shot has to judge the distance, and in doing so he may commit an error of $\frac{500}{8}$ or 62 yards. The question now is, whether this error is compensated for by the depth of the ground grazed by all the cone. In *Plate* I. will be found the depths of these zones for different ranges.

From this *Plate* we see that with a 500 yards elevation the zone grazed by the whole cone extends for 51 yards, which does not compensate for the above possible error in judging the distance, even supposing that the centre of the shot group is not displaced by abnormal or accidental influences, which, however, is usually the case in reality.

Thus 400 yards is about the practical limit for individual fire, especially as it is the limiting range at which the trajectory is under the height of a man, when aim is taken at the feet of the objective.

RAPIDITY OF FIRE AND USEFUL EFFECT.

Rapidity of fire is the possibility of firing the greatest number of shots in a given time. Many think that the value of breech-loading arms depends on the rapidity of their fire. Though we must not exaggerate the importance of rapidity of fire, yet we must take it into serious consideration. *The object is attained by reducing to a minimum the time required to load the rifle.* We must be very careful not to look upon a breech-loading rifle as an arm for rapid fire, but as a rapid loading arm, which allows a man to be always ready with it when a favourable moment comes, because *very* rapid firing is generally inaccurate and worthless, and causes a deplorable consumption of ammunition from its usually being unaimed, and, perhaps, not even fired from the shoulder especially if the firer is excited. The only case when unaimed rapid fire is permissible, is when a thick line of the enemy is very near (*i.e.*, within 200 yards).

The rapidity of fire of military rifles is nothing else than a result of facility of loading, and of being able to keep up the fire.

All breech-loading arms are either simple breech-loading or magazine arms. The former have to be loaded every time, after firing, with a cartridge taken from the pouch, the latter have a magazine, either in the butt or under the barrel, or one that can be attached, containing from 6 to 10 cartridges, which are put into position for firing by an automatic mechanical movement. *The rapidity of fire of these magazine arms is only greater than that of the ordinary rifle as long as any cartridges remain in the magazine.* After that, even if the soldier has time to refill it, the rapidity of fire in a given time becomes the same as that in a simple breech-loading rifle, at all events, with the magazine rifles that are at present before the public.

A simple breech-loading rifle can be fired about 6 to 10 times in a minute from the shoulders and with aiming. It can be fired quicker from the hip, without aiming, and by jerking the trigger. The Martini-Henry rifle can be thus fired twenty-five times in a minute.

The best magazine rifle, with its magazine full, can be fired 15 to 18 times in one minute without taking it from the shoulder, after which it can only be fired at the rate of an ordinary breech-loader.

Thus, practically, a large number of rounds, such as 100, can be fired by either kind of rifle in about the same time, 7 or 8 minutes. But with such fire we must consider the excessive fatigue that it causes, the right shoulder becomes very fatigued by the recoil, and the muscles of the arms and shoulders, especially those of the left arm, becomes unsteadied by a sort of nervous trembling; the rapidity of fire quickly diminishes, notwithstanding any muscular efforts, which tend still more to weaken the firer, and so takes from his fire any kind of accuracy, that the best shot would miss a battalion column at 100 yards under such conditions.

Experience shows that the mass of men cannot support a really rapid fire for more than two minutes, while maintaining a reasonable accuracy, that is about 20 rounds with a simple breech-loading rifle, and 26 to 30 with the best magazine rifle.

Thus, magazine arms do not lead to a waste of ammunition any more than ordinary breech-loaders, while in certain cases in war they may be most valuable, especially for the defensive, when magazine rifles would have an advantage over ordinary breech-loaders from being able at a given moment to deliver a much more rapid fire, and to pour in a greater mass of projectiles which is likely to produce a decisive effect. At close ranges, rifles of all kinds have about an equal value as regards accuracy and flatness of trajectory, and then it is that rapidity of fire must be taken into account in considering the final result.

The comparison of rifles, by their range, flatness of trajectory, and accuracy only, is not sufficient to give an exact idea of what these weapons can do in war. The value of a fire depends not only on its possible destructive power, but also on the promptitude of this action, called its *useful effect.*

The rapidity of a fire is expressed by the number of rounds expended by one man in one minute, and it is found by multiplying the total number of shots fired by 60, and dividing by the time of firing in seconds multiplied by the number of men firing.

Thus, if 82 men fire 526 shots in 1 min. 12 sec. (72 seconds), the rapidity of fire is $\frac{526}{72} \times \frac{60}{82}$ or 5·34 shots per minute per man.

The rapidity of a fire rarely requires to come up to 10 rounds a minute; 1 to 4 rounds a minute is ample as a rule, depending on the distance of the enemy.

The useful effect of a fire is measured by the probability of hitting by the rapidity of the fire, and it can be defined as the number of hits made by one man in a minute on a given object. It is found by multiplying the number of hits made by 60, and dividing by the time of firing in seconds multiplied by the number of men firing.

Thus, if 124 hits have been made in 72 seconds by 82 men, the useful effect is $\frac{124}{72} \times \frac{60}{82}$ or 1·26 hits per minute per man.

The rapidity of fire and useful effect are often calculated per 100 men.

From the above, we can see how it is that a quicker and less accurate fire may give a greater useful effect than a slower and more accurate one. As a general rule, as the rapidity of fire increases, the *percentage* of hits decreases, but the useful effect or total number of hits may be much increased.

The exclusive object of rapidity being thus dangerous to accuracy, it results that efficacy of fire only increases with the rapidity up to a certain limit, after which it diminishes, and hence we should not exclusively try to increase the rapidity of a fire nor to hurry on its execution.

We see that in calculating the useful effect we only consider the results obtained in a given time, without reference to the amount of ammunition expended.

For accuracy, on the contrary, only the results of the fire are considered without reference to the time employed in obtaining them.

In the field, against troops in column, or against any object which has depth as well as width and height, the useful effect depends also on the flatness of the trajectory, or rather the dangerous zone.

All progress in weapons tending to increase the rapidity and ease of loading, also increases both the rapidity and useful effect of fire.

Concentrated or Collective Fire.

The definition of collective fire has already been given on pp. 11 and 23, and before going further, we must warn the reader that we are going to deal with conditions which are totally different from those governing an individual fire, which we have hitherto considered.

Experiments have shown that when the ground is parallel to the line of sight, the depth of the ground struck by shots fired with the

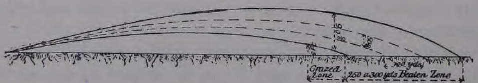


Fig. 6.

same elevation and directed on the same point is found to decrease with the distance of the object, and is called the *beaten* or *efficacious zone.** From 500 yards up to 1,400 yards (leaving out abnormal hits), it is equal to about 300 yards on an average at the shorter, and 180 yards at the longer range, if we only consider 90 per cent.

*The *dangerous zone* of a collective fire is the beaten zone, *plus* the theoretical dangerous zone of the lowest trajectory, given in Table I., pp. 4 and 5.

of hits, but if we only take the densest part of the group, including 50 per cent. of the shots, it is about 150 yards at 500 yards, and 100 yards at 1,400 yards. Over 1,400 yards the depth of the beaten ground begins to decrease very rapidly.

The width of the ground beaten when a single point is aimed at also increases with the range; if a single object of narrow width is fired at, the width of the group of hits is about 15 feet at 550 yards, 30 feet at 1,100 yards, 45 feet at 1,650 yards, 60 feet at 2,000 yards, and 120 feet at 2,650 yards for 90 per cent. of the hits.

The surface of the horizontal group, which contains 50 per cent. of the hits, is called the *nucleus* of the group; that which contains the next 40 per cent., *the envelope of this nucleus*; and the hits produced by richochets and the remainder of the shots is called the *tailing*.

The centre of the nucleus is the point of mean impact of the horizontal group, and round this point the hits are most congregated.

Just the same as it is necessary in an individual fire, that the point of mean impact should coincide with the object to get the best result possible, so in a concentrated fire the densest part of the nucleus should fall on the object to be hit, and hence, in dealing with concentrated fire, an exact knowledge of the range is almost as necessary as for individual firing.

The longer the range, the more vertically the bullets drop, and therefore the less dangerous is the beaten zone, or the efficacy of the fire from a given number of men. As the space over which 50 per cent. of the bullets falls remains nearly constant, this efficacy for different ranges can be relatively measured, by the horizontal distance passed over by a bullet, near the centre of the nucleus, at the end of its flight, divided by the vertical height through which the bullet falls at that distance. The numbers thus obtained are given in column 6 of the trajectory table, given on p. 4, and from this table we see that a concentrated fire at 1,700 yards will have only half the efficiency of one at 1,200 yards, and one quarter of one at 800 yards, and one eighth of one at 500 yards. This is supposing that the lateral dispersion remains constant as well as the longitudinal dispersion, which we know is not the case. Taking the lateral dispersions given above as correct, the lateral dispersion at 1,700 yards is three times, and at 1,200 yards is about twice that at 500 yards, so that the efficiency of a fire at 1,700 yards is only about one twenty-fourth, and of one at 1,200 yards is only about an eighth, of that of one at

500 yards. This statement is far from being absolute, but it is only given as an example to show how the efficacy of the concentrated fire of a given number of men rapidily decreases with the range.

Thus, at *known ranges*, to get a similar effect by a concentrated fire at 1,200 as at 500 yards, we must employ a considerably greater number of men, or rather, amount of ammunition, than the number required to get the same effect if the same object is only 500 yards off.*

Now, besides the efficacy of the fire decreasing so rapidly with the range, it gets at the same time harder and harder, as the range increases, to estimate the exact distance, both of which conditions tend to make the fire less and less efficacious as the range becomes longer, so that there is a limiting range, after which any fire, although concentrated and aimed, really becomes hap-hazard, or as it may be called "chance fire," however carefully the man may aim. Neither this limiting range, nor the result of such a fire can well be definitely stated, but experience has shown that when a "chance fire" was kept up by a mass of men at even such long ranges as 2,000 yards, it proved very terrible in 1877-78 to the Russian troops in any deep close-order formations.

If the range can be found by any means to a certain percentage of the truth, then a body of men all using the same elevation should not fire at a longer range than that at which *twice* the given percentage of error is greater than the beaten zone for the range. Beyond this limit an efficacious fire cannot be ensured, and ammunition is likely to be wasted, that is, too many bullets will be expended for the amount of good gained, which bullets would have been better kept for a shorter and more effective range.

We must, therefore, inquire what is to be taken in our calculations as the extent of the beaten zone? Is it to be the extent of ground struck by 90 per cent. of the bullets (300 to 180 yards), or that struck by 50 per cent. of the bullets (100 yards)? The latter value, being almost constant, has been accepted by all Continental nations, and as they have experience, and we have none, we cannot do better than accept their conclusions as to what should be considered as the total beaten zone for all ranges over 400 yards up to 1,400 yards;

* In battle, for moral reasons, it is better to expend the required ammunition as rapidly as possible by increasing the number of men firing. Sudden losses intimidate the enemy more than if the losses were more gradual; to expend the necessary amount of ammunition by making a few men fire a long time, takes all the offensive spirit out of them.

under the 400 yards range a concentrated fire is hardly ever possible, as it becomes perforce a frontal individual fire from the excited and uncontrollable state of the men.

This central beaten zone of 100 yards, formed by the nucleus of a concentrated fire, is a very fair estimate, because when the effect of ricochets is considered, 50 per cent. of the shots is a very fair allowance to take of the total number of shots. To try and utilize the whole zone of 90 per cent. of the shots would be pushing theory almost too far.

If we have no range-finder, and cannot get the range from the artillery, or from maps, or by watching the strike of the bullets, or by any other means, the only way of getting the range of an object is to judge, or rather guess its distance. Judging distances is a very difficult operation from so many physical circumstances affecting the eyesight, so much so that a possible error of one-eighth of the estimated distance may occur in judging the range by eye, and hence the error may be within one-fourth of the range.

This limit of one-fourth the range, would require that, when all the men use the same elevation, and when the ranges are estimated by eye alone, a concentrated fire should not be opened at a greater range than four times the constant beaten zone of a concentrated fire (4×100) or 400 yards, but concentrated fire at such ranges is not required from the accuracy and efficacy of individual fire within that limit, and from the flatness of the trajectories of the military rifles at present in use in all Continental armies.

Now the only way to get certain results at ranges over 400 yards, when the range is estimated by eye, is to divide up the body of men firing at a given object into two or three or more equal parts, as the case may be, and to make each sub-division use a different elevation at the same time. By this means, with a given number of men, a greater depth of ground is swept, though with a less intense fire than if one elevation is used by the whole body. The number of elevations to be used depends on the range and the constant beaten zone of 100 yards at each range. The greater the range the greater is the probable total error of judging it, and therefore the more elevations should be used, and also if the same intensity of fire is required at each range the greater, in the same proportion, should be the body of men firing, or rather the quantity of ammunition expended, than the number required if the range is known.

The number of elevation to be used is also somewhat governed by the consideration of the depth of the object fired at, and as to whether it is stationary or moving.* If the object, with no depth, is stationary the range can be found with fair accuracy by watching the effect of concentrated fire on the enemy, whether with a given elevation it has any effect on decreasing his fire at the point aimed at, or by watching the strike of the bullets where the ground is favourable for such a course. In such a case only one elevation, or two at the most, would be required. Against very deep formations, as a battalion column of fours, which allow a considerable latitude in judging the range, because it does not much matter if the head or rear of the formation is hit, fewer sights are required than against shallow formations. But if the object is moving, and so constantly altering the range, a greater number of sights are required than if it is stationary.

But let us take the extreme cases, and then we shall know what we have to reduce in more favourable circumstances. As the beaten zone of a concentrated fire for different ranges is constant and equal to 100 yards, we see that to obtain a continuous beaten zone with the combined use of different sights, these sight must differ from one another by more than the elevation for 100 yards.

Thus, when two elevations differing by 100 yards are used we get a beaten zone of 200 yards, and so when the range is guessed by eye, and we may have a probable limit of error of one-fourth the estimated range, a body of men should not fire at over (4 × 200) or 800 yards.

Similarly, when three elevations, differing by 100 yards, are used, we get a beaten zone of 300 yards, and under similar circumstances as above a concentrated fire should not be opened in this case at over (4 × 300) or 1,200 yards. From what has been said before we need not consider ranges over this.

The usual rule for the use of two elevations is, that one elevation should be for 50 yards under, and the other for 50 yards over, the estimated range; and for three elevations, it is that one elevation should be for the estimated range, one for 100 yards under, and the third for 100 yards over it. In the latest German regulations, it is stated that when the ranges are guessed, and a stationary object is fired at, two sights, differing by 50 metres will be used for ranges between 400 and 600 metres, and two sights, differing by 100 metres, for ranges between 600 and 800 metres; if the objects are moving, then for ranges over 400 metres, several sights differing by 100 metres will be made use of.

* For this purpose it is just the same whether the men are stationary and the object is moving, or *vice versa*.

Thus, three elevations is, as a rule, the most that is ever required to be used in practice, but we ought always to try and avoid firing under such conditions when possible, from the comparatively great consumption of ammunition which such a use of different elevations must cause, unless very favourable objectives present themselves, and the available ammunition is more plentiful than is usually the case.

The combined use of different sights can also be employed to neutralise the influences of the atmosphere, and the nature of the slopes of the ground in the neighbourhood of the object. (See p. 115.)

Thus we see that two or three elevations, used simultaneously, give an effective fire-swept area having a depth which varies from 200 to 300 yards. It is clear that this result is only obtained with a given body of men at the expense of a diminution of effective fire on any given point of the fire-swept area, and therefore to bring up the effect of the fire it is necessary either to fire more rapidly so as to burn more cartridges, or to attain this end by increasing the number of men employed, in order to obtain the desired effect without prolonging the duration of the fire. *Prolonged firing ought always to be avoided, in order not to weaken the moral effect which musketry fire ought to produce by means of sudden losses rapidly inflicted.*

The ranges of 400, 800, and 1,200 yards given above for the combined use of 1, 2, and 3 sights respectively, agrees very nearly with German practice, and suits the construction of the backsight of the Martini-Henry rifle.

The Germans divide the space which extends between any two hostile forces into three zones.*

(1) *The short zone*, comprised between the muzzle and a distance of 440 yards (400 metres.)

(2) *The medium zone*, which comprises distances between the short zone and a distance of 770 yards (700 metres.)

(3) *The long zone*, which comprises distances between the medium zone and a distance of 1,320 yards 1,200 (metres.)

When the range is not known and has to be estimated by eye, or when one side is in movement, and when the atmospheric influences and the slopes of the ground near the enemy are not favourable, the Germans employ one sight for ranges in the short zone, two sights for ranges in the medium zone, and three sights for ranges in the long zone.

* The Germans consider that the beaten zone of a concentrated fire extends for 100 metres or 110 yards. If we use this depth instead of 100 yards in the above calculations, we obtain the following distances used by the Germans.

With regard to the least number of men with whom combined sights should be used, the Germans insist that the body of troops employed should be at least a "zug" (which on a war footing is equal to 80 men at least, or an average English company), and the Italians say a section of 60 men, when two sights are used, but both say that a company (250 men) should be employed when three sights are used. This comparatively great increase of men is due to the rapid decrease of efficiency of concentrated fire with the range, as has already been explained. In Germany, when two sights are used, the two ranks of the "zug" each use one, and when three sights are used, each "zug" of the company use one, their being three "zuge" to a company.

An English company, formed up in two ranks, is sub-divided into two half-companies of two sections each. Hence, when three elevations are to be used, it would be inconvenient to employ an equal nnmber of men to fire with each sight. In this case it would be best to make two sections of the company use the elevation for the presumed range, and the other two sections each to employ, one the elevation for 100 yards over, and the other the elevation for 100 yards under, the supposed range. Or, if it is laid down that when two sights are to be used, a whole English company must be employed, and when three sights, three English companies, then each half-company or company should be made to use one. Each rank should not be given a different sight, as it makes it more difficult to see that the men are using the proper elevation than if each unit of men used the same one.

Generals Von Boguslawski and Kampe, however, are no warm advocates of combined sights, especially at long ranges, and the latter says "all tricks of fire are opposed to sound tactics. Long range fire with combined sights, as well as indirect fire (see p. 82), only lead, in the open field, to waste of ammunition. These methods, however, may be advantageously used in siege warfare."

In spite of criticisms of the above well-known German military writers, it is only fair to say that the German infantry do not use a combination of sights when the range is known within 50 yards, when neither opponent is moving, or when the atmospheric conditions, and the slopes of the ground in the neighbourhood of the object aimed at, are such as to only affect the practice slightly.

The Germans do not question the advantages of accurate aiming, as might well be supposed from their use of different sights. The depth of the fire-swept areas would be much more than 100 yards if the men did not aim. Random firing would, therefore, overturn the whole system of fire which they have adopted.

Another point must be referred to here so as to prevent any misconception of ideas, for though the reasons for it will be entered into more fully further on, yet the results have already somewhat entered into our present considerations. From the undoubted advantages of a *concentrated* fire as regards its efficacy and the possible *control* over it, it must be kept up as long as possible; so intimately are these connected that concentration of fire is only possible so long as control is possible, and the limit of such control with disciplined troops may be put at 400 yards from the enemy. Nearer than this, and often at a longer range, the men are too influenced by the moral excitement caused by the enemy's fire, the noise, the cries of the wounded, and the sight of the dead, etc., to be controlled at all, and a rapid independent fire is then involuntarily delivered straight to the front of the extended mass. No order can prevent it. This change from concentrated to independent fire is not sudden, but has been gradually coming on as the power of control has decreased, and must be expected to cease entirely at about 400 yards from the enemy, when the men will fire only to their direct front ,and will only be influenced by the training and discipline they have had in their peace training, and by the personal example, and not by the words, of their leaders.

INFLUENCE OF GROUND AND OBSTACLES ON THE EFFECTS OF INFANTRY FIRE.

All that has been hitherto said, as regards the effects of musketry fire, refers to fire falling on ground, which, at the point where the bullets fall, is parallel to the line of sight, whether the latter be horizontal or inclined. But in reality the effect of the fire with regard to the dangerous and beaten zones, and the effects of ricochets, vary very considerably with the nature, shape, and peculiarities of the ground on which the bullets fall. It is very important to study these different effects as well as the circumstances which increase or lessen them, because it is only by such information that a rational use of the fire can be made, and that tactical dispositions can be chosen which offer the least chance of being destroyed by the fire of the enemy.

Before proceeding further, it is as well to make some preliminary statements to prevent confusion and to insure simplicity. In the following pages by "*rising ground*," and "*falling ground*," we shall mean ground at the point where the bullets fall, rising or falling, in the direction of the fire, *with respect to the line of sight*, and we shall suppose it, unless otherwise stated, to extend for such a distance as to influence the whole dangerous zone. It may be remarked here that such rising ground is always visible, while the falling ground is invisible, to the firers.

The *apparent crest* of such rising or falling ground is the point where the line of sight forms a tangent to the ground, and hence the position of this crest depends on the position of the origin of the fire; as the position of the origin of the fire alters, then there is a different apparent crest for each position.

A fire is more or less *grazing*, with reference to a given slope of ground, according as the bullets pass over a longer or shorter extent of ground under the height of the objective above it, thus rendering dangerous a more or less considerable space.

The *dangerous zone* for an object of given height and for a given trajectory is, as we know, the extent of ground over which the given object can be struck by the given trajectory, and therefore the maximum dangerous zone is attained when the height of the trajectory above the ground, at any point along the range, does not exceed that of the object fired at, in which case the length of the dangerous zone will extend from the muzzle of the rifle to the point of impact of the bullet on the ground, and beyond this point also if the ricochet is considered.

The elements on which the extent of the dangerous zone depends are (1) the flatness of the trajectory, (2) the range, (3) the height of the object, and (4) the slope of the ground on which the fire is directed. The flatter the trajectory, the less the range, the greater the height of the object and the more parallel the ground is to the angle of fall of the bullet, the greater is the dangerous zone, and vice versa.

It is easy to see that when the bullets fall on rising ground the length of the dangerous zone decreases according to the steepness of the ground (see *Fig.* 8). But if the bullets strike on falling ground the dangerous zone is increased, and is at a maximum when the slope of the ground beyond the crest is just the height of the objective from the trajectory. Thus the increase of the dangerous zone, caused by different slopes of ground, is not indefinite, because as soon as the ground falls more than stated above it is no longer grazed by the bullet along its whole length. The total dangerous ground includes the grazed ground as well as the ground struck by the bullets. The depth of ground grazed is nothing else than the dangerous zone caused by the lowest trajectory. It is on this condition of grazing the surface of the ground, under the height of the objective, that the total length of the dangerous zone depends.

Thus we see that at the short ranges, for which the trajectories, are very flat, the ground which gives the greatest dangerous zones is that which falls only slightly behind the object fired at. At the long ranges, on the contrary, where the curvature of the trajectory is much more accentuated, ground falling more and more rapidly, as the range increases, will be more favourable.

The depth of ground that any obstacle shelters from the bullets fired at any given distance, is called *the defiladed zone of the obstacle at the given distance.* This zone is the space which extends from the crest of the obstacle to the point of impact, on the ground, of the trajectory which grazes the crest or top of the obstacle. If the obstacle is higher than a man, the latter can only be hit towards the end of the defiladed zone furthest from the obstacle, when the bullet passing over the crest comes within his height from the ground, *i.e.*, when it grazes the surface. Thus the grazed part only of the defiladed zone is dangerous, and consequently the *protected zone* is less than the defiladed zone by the extent of the grazed zone.

The higher the obstacle, the greater are the defiladed and protected zones for a given range and given form of ground on which the obstacle stands.

When the height of the obstacle is less than that of a man, the protection it affords is only partial. Whether complete or partial, the protection afforded by obstacles, on any ground struck by bullets, has the effect of considerably diminishing the efficacy of the fire.

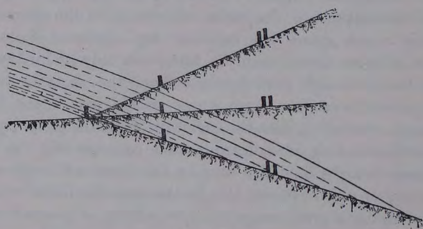
The defiladed and protected zones increase or decrease under the same conditions as those which cause the extent of the whole dangerous zones to vary. Thus they diminish as the range increases, and they increase as the height of the obstacle increases.

As the ground rises or falls with respect to the line of sight, the defiladed and protected zones are respectively decreased or increased for a given range and given height of the obstacle.

Although the extent of ground, beaten or rendered dangerous, varies according to its inclination to the line of sight, yet the trajectories of the bullets can in no way be influenced by the ground itself, and hence a vertical object, situated in the group of falling bullets, will always be equally liable to be struck, whatever may be the inclination to the line of sight of the ground on which it stands.

Thus the results of a fire on a thin object without depth, such as a line formation for example, are not modified by the inclination of the ground. This line formation presents at all distances, and on whatever ground it may be, an objective of an almost invariable height.

But this is not the case for echeloned or deep formations as a whole. Taking first the case of echeloned formations, a second line, in order not to be under the same fire as the troops in front, ought to be so placed in rear as to be out of its dangerous zone; thus its distance should be regulated by the inclination of the ground on which the bullets fall, and by the range, which latter effects the flatness of the trajectory and the angle of fall of the bullet.



Fig, 7.

A battalion in attack formation will not, therefore, have the same relative security in all kinds of ground. If the whole of this formation occupies 600 yards in depth, all the echelons may, in a favourable case, be comprised in the same dangerous zone on ground falling with reference to the line of sight, whilst on rising ground

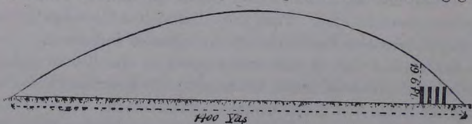


Fig. 8.

the rear echelons will not be struck by the fire directed on the first line. Hence it may sometimes be advantageous to deploy a force on ground sloping towards the enemy, especially if it has a steep slope, rather than on the reverse slope if this latter be very gentle; that is, troops may often be safer on the exposed surface of a hill than on the reverse side of it.

With regard to deep and closed formations, such as an English company column of 80 men in fours.* they are, as regards vulnerability, equivalent to vertical objects of greater height as the range increases. Such a column at 800 yards is represented by a vertical

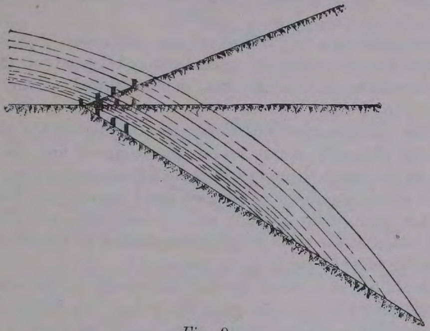


Fig. 9.

object 11 feet in height, and at 1,400 yards by an object 19·6 feet in height on ground parallel to the line of sight. It thus has a considerable vulnerability, the amount of which will vary also with the inclination of the ground; and in *Fig* 9, we see that this formation will experience less losses on a slope falling, with regard to the line of sight than on ground parallel to, or rising with regard to, the line of sight.

This effect is most felt on ground which falls sufficiently to allow the trajectory which grazes the crest to leave a defiladed zone behind it.

On ground rising with reference to the line of sight, the same formation on the other hand comes under very different conditions, for it is then struck by bullets which would have passed over them on ground parallel to the line of sight.

On ground falling with regard to the line of sight the grazed zone is increased, but it is impossible to observe the strike of the bullets

* The company is taken as having opened out one-third of its length, *i.e.*, it occupies about 36 yards in column of route.

to regulate the fire by, and hence this effect of the fire depends almost entirely on chance, as we are trying to hit invisible objects.

It is, however, important to know the grazing effects of fire on ground falling with respect to the line of sight, so as to obtain as much of it as possible; but, if it is intended to make use of this kind of fire, we must expect to sacrifice accuracy of fire in trying to produce these grazing effects on supposed or unseen objectives.

A grazing fire is a very efficacious one, and covers a great extent of ground, but the amount of ground covered depends on the range, on the elevation, and on the form of the ground at the point of impact of the bullets.

A little consideration will show that the higher the ground on which the objective stands above the origin of fire, the greater should be the range, to produce the same efficacious fire from grazing. Thus, to obtain an efficacious fire, we must have a good idea of the reliefs and slopes of the ground; but the same efficacious effect is not only to be got at the exact range corresponding to these conditions, but also for some 50 yards under and over it.

To obtain the same effect on different slopes, at the same height above the origin of fire, the men firing must go further from the crest, according as the inclination, with respect to the line of sight, of the slope in rear of it gets greater.

The fire becomes eccentric when it is delivered from a point nearer than the proper distance corresponding to each slope and difference of level, that is, a protected zone is created in rear of the crest fired at.

Ricochets.

The amplitude of the ricochets is increasd by a ground falling as regards the line of sight, and decreased by ground rising as regards the same line.

Generally ricochets go to a greater distance, as the angle of drop of the bullet with regard to the ground is smaller.

When the ground is of average hardness this angle should not be greater than 15° in order that the bullets may ricochet.

Soft ground, or ground covered with thick vegetation, or with a surface cut up by transverse projections or furrows stop the greater number of the ricochets. A soil hardened by frost or a firmly-set sand are, on the contrary, eminently fitted to make bullets ricochet.

If the profile of the ground on which the bullets fall short, has a slightly concave or hollow form (see *Fig.* 10) these bullets will ricochet on to the object. But if the profile of the ground is convex, as in *Fig.* 11, they are likely to pass over the object. A round crest in front of the object gives, therefore, a good protection against ricochets.

Fig. 10.

Fig. 11.

The appearance of dust thrown up by the bullets in ricocheting, facilitates the observation and correction of the fire.

In firing down hill, or into the face of a hill, there may be no ricochets.

Stony ground makes the ricochets very variable, and causes splinters of stone to fly about.

One thing that must strike every one after a study of the foregoing pages, is the great importance which must be now-a-days attached to *the knowledge of ground and its employment*, in knowing its use offensively and defensively, and its effect on the fire, both in the attack and defence. The value of ground is not absolute; it not only varies with the nature of the arm, with their range and combinations, but it depends also on the actual positions that the troops occupy on it. "A knowledge of the ground is no less indispensable for the attack than the defence—here to profit by some strong points, there to avoid them. The ground dictates to the defence the points of resistance and the tactical dispositions; it indicates to the attack the directions in which a bayonet attack has no chance of success, and those where it can succeed. . . . Tactical dispositions ought to be based on the properties of the ground; an ideal formation on a horizontal ground would be annihilated if it were blindly placed in intersected and varied ground; there does not exist any panacea applicable to all cases."

Plunging, Curved, or Dropping Fire.

Obstacles forming a covering mass furnish a more or less considerable protection according to the height of the obstacle and the range.

Therefore, to hit an enemy behind a shelter, the men firing must be placed at such a distance that the bullets rise high enough in their trajectories to fall with a high angle of drop, and so to diminish the depth of the defiladed zone, by plunging or dropping, so to say, behind the obstacle. This kind of fire is called a *curved, or plunging, or dropping fire.*

The efficacy of a dropping fire depends on the angle of drop of the bullets on striking. On looking at the trajectory table, pp. 84 and 85, we see that at 800 yards an object eight feet high covers on ground, parallel to the line of sight, a depth of $8 \times 21{\cdot}2 = 169{\cdot}6$ feet in rear of it, and at 1,400 yards only $8 \times 7{\cdot}87 = 63$ feet in rear of it, so that the troops in line immediately in rear of such cover would always be safe from infantry fire, and even if they did suffer they can evade it by moving to the right or left as the enemy cannot see them nor the effect of their fire. The greater the angle of drop, the greater is the *searching power* of the fire, as it is called.

Thus to ensure effective results from a dropping fire in the field, the range, the direction of the object, and the nature of the ground in rear of it must be accurately known, and if the distance is not suitable, the range must be altered. But this can only be done when there is plenty of time at disposal, as in a siege where the objects fired at are stationary, and thus very favourable for a dropping fire. But such a fire may even then be ineffectual if the defenders are well provided with traverses, blindages, etc., etc. Under ordinary circumstances, however, in an engagement in the open field, a dropping fire is of little practical use.

A dropping fire, as said above, can under favourable circumstances render great service in sieges; but it can only be employed with some efficacy by placing the men at sufficiently great distances from the obstacle.

Siege and rampart batteries have, as a rule, an average height of about eight feet above the fighting terreplein. At a distance of 1,000 yards, and for an obstacle 8 feet high, the defiladed zone has a depth of 117·6 feet, while protected zone for a standing man has a depth of 29·4 feet only. Thus, to hit a standing man on the terreplein, which is generally about 30 feet wide, the men firing should be placed more than 1,000 yards from a covering parapet, 8 feet high.

It is necessary also to use an elevation rather greater than for the exact range, so that the centre of the nucleus or the central trajectory may pass slightly over the crest of the obstacle. It is sufficient for this purpose to aim at the crest of the obstacle with the sight for a range of 25 or 50 yards greater than the exact range.*

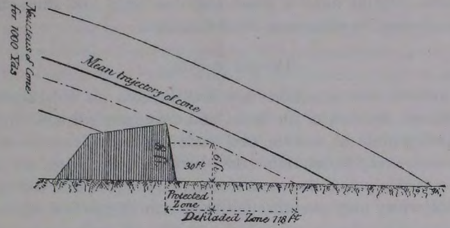


Fig. 12.

In siege trenches, the protected zone against a fire at 2,000 yards, perpendicular to the crest, extends, for a standing man, to the rear of the trench; thus it is not possible to sweep these trenches by a fire directed perpendicularly to this crest.

Thus, in order to search out these works, it is necessary to fire at the crest in the most oblique direction possible. In fact, we see that if the fire is executed in the direction BD (*Fig.* 13), obliquely to the crest XY, instead of in the direction AD perpendicular to it, the

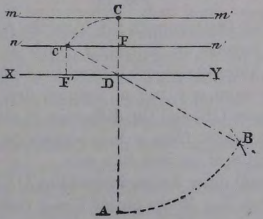


Fig. 13.

lowest trajectories of the cone of bullets, passing over the parapet, strike at C′ instead of at C. The defiladed zone is consequently diminished by the quantity CF, and the zone between the lines *mm′* and *nn′*, which was sheltered from fire perpendicular to the crest, will be beaten by the oblique fire.

* As a concentrated fire would always be used for indirect firing, 50 per cent. of the bullets would always be spread over 100 yards. This will eliminate any theoretical error from using a too great elevation.

If the trenches or lines of fortifications are not provided with traverses, and can be taken in enfilade, it is not necessary that the trajectories should have a great angle of drop, and thus such an enfilade fire can be efficacious at all distances.

Indirect Fire.

By indirect fire is meant any fire directed on objects that are masked from the view of the firers, and are at some distance in rear of the covering obstacle, and the problem of indirect fire reduces itself to this case—viz., to determine the elevation with which one should aim at a visible point, chosen as an auxiliary object, in order that the mean trajectory may pass through the centre of the real object.

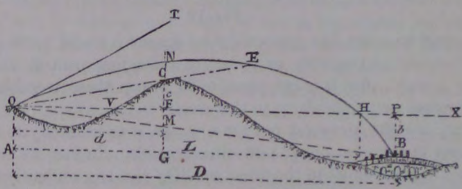


Fig. 14.

Suppose we wish to cover with fire from the point O *(Fig.* 14*)*, an object B placed beyond an obstacle C, such as a crest, a wood, a wall, &c., which hides the object B from the sight of the firers at O.

To be able to make any use of indirect fire, the direction of B from O, the distance OB, and the difference of altitudes of the points O and B must be known from a map drawn to a scale of at least $\frac{1}{80000}$, or about $\frac{3}{4}$ths of an inch to a mile.

From the point O draw the horizontal line OX; this line cuts the covering obstacle in V. If the object B was visible from O, it would be necessary, in order to hit it, to aim at it directly with the angle of elevation TOB; but the object being hidden, it can still be struck by aiming at an auxiliary point V, situated in the horizontal OX passing through O.

Instead of aiming horizontally, which offers certain difficulties, we can with advantage use the crest C of the obstacle, as a point or line to aim at.

In this case, it is necessary to aim at the point C, with the angle of elevation TOE. We must now find on the line OC produced, the position of the point E where the trajectory cuts this line, that is to say, the distance OE, so as to find from it the sight to be used. To do this, we have

The angle of elevation TOE = TOB − EOB = TOB − (EOH + BOH).

The values of these angles must be found by calculation, by means of measurments from a contoured map and Table I. on pp. 84 and 85. The tangents of the angles EOH and BOH are found by means of the elevations of the points C and B above and below O, and their distances from O. Then their real values are found from the column 3 of tangents given on p. 84. The angle TOB is the angle of elevation for the total range.

The error in this calculation will always be within 50 yards, which does not matter, as the bullets of a concentrated fire fall over 100 yards.

The above method of solving the problem of indirect fire depends on all the relations of height and distance between the three points, which have to be considered in indirect fire, being known; but this will only occur in the defence of fortresses and positions prepared beforehand. In the field, the application of indirect fire must be limited to those cases in which the determination of the three points in question can be instantaneously known or estimated with sufficient accuracy. These cases occur when a mounted commander, or one who can place himself in a tree or other high point of observation, can see the enemy when his troops standing on the ground cannot do so. In such cases, the easiest method to make use of indirect fire is to employ columns 1, 2, and 3, of Table I., in connection with an easy calculation in the manner already shown. The difference of level in yards between the point aimed at and the height of the rifles above the ground, must be estimated or found with a clinometer and the distance of the same point in yards estimated or measured. But it must never be forgotten that the efficacy of an indirect fire depends on whether or not its effects can be seen, so as to correct the fire. If it cannot, then, in the field, when the supply of ammunition is limited, it is useless to attempt to make use of this kind of fire. It is often possible to post an officer on the covering mass* for this very purpose of observing the fire; he would, of course, be to one side of the direct line of fire.

Indirect fire, however, can rarely be used in the open field.

* If the covering mass is a hill, and is quite close in front, *i.e.*, 200 or 300 yards off, it would of course be occupied in preference, when possible, and a direct fire made use of.

In defensive positions, and principally in sieges, indirect firing can render great service. But, in order to obtain every advantage from it, it is necessary that the ground over which it is executed should be well known, that some marks should have been put up, and that the altitudes of the different points, as well as their distances apart, should have been measured. This information for the environs of fortified places should be written down in *Firing Tables.*

A firing table contains all information on the different probable points of passage of the enemy (bridges, cross roads, defiles, débouchés, etc.), as well as the corresponding convenient situations for the firers of the defence. It contains also, for each station, the point to be aimed at and the sight to be used.

Thus we see that indirect fire requires the previous knowledge of certain topographical data in order to determine the point to be aimed at, and the sight to be employed. In the offensive, an occasion to use it will rarely be found; but cases for employing it may occur in the defensive, when there has been ample time to prepare the position and study the ground in front of it.

In siege warfare, however, it may be applied, and be made to render very great services to both the troops of the attack and of the defence.

But indirect fire can only be carried out in the field when, by the aid of a sufficiently accurate map, the position of the objective, of the auxiliary point aimed at, of the origin of fire, and of the alignment of these three points are known, as well as the horizontal distance which separates them, and their differences of level. From these data the sight to be used can be determined, which in some cases can be rectified by watching the strike of the bullets.

Another thing we see is, that indirect fire can only be used when the ordinates of the trajectory are sufficiently great to allow of it passing over the height or obstacle which prevents the object being seen, and hence to execute an indirect fire the origin of the fire may have to be moved further away from the object to be hit in order to get greater ordinates. Again, as the powder charge, and consequently the muzzle velocity and angle of elevation for any given range, cannot be altered in rifle ammunition, we cannot fire indirectly on an object unless the range is suitable.

Resumé.

Thus, though long range fire can be executed on unseen objects, yet it necessitates a thorough knowledge of the ground, and of other particular conditions, and hence this nature of fire is impracticable in war, except in two special cases :—

(1) When the fire is inclined, by which, when firing from a valley or plain on to the crest of a plateau, a dangerous zone is obtained by indirect fire much deeper than on ground parallel to the line of sight, by which the direct shots, aimed on the shooting line occupying the edge, may strike the supports and reserves in rear. When, however, the defender withdraws himself from the edge of the plateau, the power of using inclined fire passes to the defender, who then, by his direct fire on the enemy's shooting line when it reaches the crest, may cause loss to the enemy's echelons in rear.*

(2) When the fire is dropping, the objective being a fortification; but the effect of this fire will be somewhat modified by the modern use of traverses and blindages.

It is in fortress warfare, as pointed out by Von Boguslawski, and chiefly on the side of the attack, that a long range dropping rifle fire will be principally used in the future. The infantry of both sides will no longer be reduced, as of old, merely on the one side to fire on the attacker's sap heads, and on the other on the defender's embrasures to keep down his artillery fire by harassing and decimating his gunners. But it will have in the future a more extended *rôle*; infantry can now combine its fire with that of the siege artillery, and help it by sweeping the ramparts and rendering them for a time untenable by the garrison.

This use of rifle fire seems destined to give important results against detached forts, and more especially so against isolated works, particularly those which can be surrounded, when detachments can be so placed as to enfilade the faces of the works and compel the garrison to get under cover. The musketry fire from the ramparts of modern forts is often very weak from the number of traverses and guns which take up so much space, and hence the fire of the attacking infantry, putting artillery fire out of consideration for the moment, can only be returned with effect from the covered way or from shelter trenches placed in front of the works, or from a low parapet placed in front of the main ramparts, affording to the infantry sufficient space to deploy. If the Russians had employed long range fire in the manner indicated above at Plevna, it would have considerably facilitated their attacks.

It has been already stated that long range infantry fire should be

* The question of the occupation of a position on account of these theoretical facts is at present a very debatable question, and so has been omitted.

concentrated and used by masses (*i.e.*, large bodies of troops) only, and if used judiciously in such a manner it must prove of the greatest advantage in fortress warfare, and will be a great assistance to the fire of artillery.

In a siege, long range fire being used by well covered detachments at ranges exactly known, and on a clearly defined object, very easy to aim at, with the rifles being rested on boards, etc. (see *Figs.* 15 and 16, p. 131), its results cannot be compared with such fire in the field where the infantry are exposed to all the excitement of battle, and where the fire has to be directed on a moving adversary who can only be seen at short intervals, at unknown or imperfectly known and continually varying ranges, and at no clearly defined objective. Again, in siege warfare the siege train of the attack can bring up an unlimited supply of infantry ammunition, while the supply of ammunition to attacking troops in ordinary field warfare is a very difficult problem to solve satisfactorily. A body of infantry, extended in prolongation of the face of a work, could, by the use of several sights, cover its whole extent with fire. An enfilade fire dropping about 1 in 14, (from 1,000 yards) and a plunging fire of about 1 in 4 (from 2,000 yards) could be used together on a fort; they would prevent the garrison from moving freely on the ramparts, and would take in reverse its rear faces even over any parados that may exist. If every man fired 100 rounds per hour, a battalion of 800 muskets would pour into the fort a mass of 160,000 bullets in the space of two hours, which could not but have a most telling effect, unless the fort possessed more than the usual amount of casemates and blindages.

At the commencement of an attack on large entrenched camps, the *rôle* of infantry will also now-a-days be still more considerable than formerly. The detached forts surrounding such camps will be joined by lines of trenches and batteries of position. The besieger, by appearing suddenly before the place, and by seconding the fire of his first siege batteries with a heavy infantry fire, may be able to so sweep the ground between the two or three forts chosen for attack as to prevent the besieged from maintaining or reinforcing these intermediate lines. Under these circumstances, Von Boguslawski thinks that the besieger may be able to penetrate by main force through the line of exterior defences, and completely surround one of the forts, when it can be attacked like an isolated work, in the manner described above. To effect this purpose it is of course assumed that the besieger can dispose of greatly superior forces, and so to employ infantry in masses against the intermediate lines of the defence will, it is considered, be the most effective manner of using the preponderating force.

This is in principle nothing but a reproduction of the ordinary conditions of an attack on a defensive position in the field—a heavy fire disorganizing the defence and preceding the assault. This distant fire from not having the same efficacy as fire at shorter ranges, and from entailing a great consumption of ammunition, should only be looked upon as a help to the artillery to disorganize the defence and so prepare the assault. Under these circumstances, the passive obstacles presented by fieldworks being but slight, the lines which a distant fire have compelled to be more or less evacuated may very possibly fall before an attack rapidly executed in great force.

Against the forts themselves these results will be much less, since distant infantry fire, although it may inconvenience the defenders, cannot prepare the assault, because even supposing the defenders driven from their parapets, the assaulting columns would be stopped by the passive obstacles (deep ditches, scarps, etc.) undestroyed by artillery fire, where they will be fully exposed to the unsubdued fire of the flanking defences. This does not of course apply to works without any ditch flanking defences, such as the Turkish defences at Plevna, and which were therefore open to assault.

Even if it be impracticable to employ infantry in the above vigorous manner, yet there can be no doubt that the duties of infantry at the commencement of sieges will be much transformed and developed in the future. Hitherto its action has been more passive than active, the duties of infantry having been chiefly confined to investing the fortress and protecting the exertions of the first batteries, but now owing to its improved weapons its action will become more active. For this reason, Von Boguslawski insists upon the necessity of instructing both officers and the rank and file in this employment of fire, and proposes to create a special siege infantry, just as there is a siege artillery.

A writer in the German military paper, the *Militär Wochenblatt*, for February, 1885, in discussing the question of indirect infantry fire, is of opinion that its effect in the field is generally open to question, as it leads to great expenditure of ammunition with but doubtful results. The modern rifle, he considers, with its low trajectory, is seldom suited to its employment, except at long ranges, and where troops are known to be concealed in shallow depressions of ground;

on the other hand, if operating against troops protected by siege works or field entrenchments, direct rifle fire is of but little use, unless the enemy exposes himself above the parapet, and the only means of reaching the mass of men who are sheltered within the works is by employing artillery fire. It is much to be desired that some means should be devised to make rifle fire effective under such circumstances. The profile of ordinary siege works protects the men against fire with a less angle of descent than 15°, and as the rifle, even at a range of 1,700 yards (the maximum distance for which the German rifle is sighted), has only an angle of descent of about 11° to 12°, it is of little use against men under cover. The maximum range of the rifle is reached with an elevation of 35°, and any attempt, with the present ammunition, to use it with greater elevations, so as to clear the parapet at shorter ranges, would probably prove futile on account of the height to which the bullet would rise, and the increased resistance of the air making the fire uncertain. Hence the writer of the article referred to above thinks that experiments should be made to ascertain whether this inconvenience could not be overcome by employing a special cartridge with a reduced charge of slow-burning powder. The advantage that would be derived from the employment of indirect infantry fire during siege operations, when the distances can always be accurately ascertained, is so great that this suggestion is worth consideration.* It would, of course, be necessary to have a supplementary sight, that would allow of the proper elevation being given for certain ranges, and precision might further be secured by firing the rifle from a rest. The additional sight need not form a permanent feature in the rifle, but need only be attached when required.

Direct and Indirect Aiming.

From the foregoing we see that any kind of fire can be executed in one of two ways :—

1. By aiming directly at the object to be hit with the proper sight for the distance, called *direct aiming*.
2. By aiming at an intermediate object, in line with the object to be hit, with such a sight as will ensure the given range—

* Artillery has had to solve the problem of using guns for both indirect and direct fire in sieges, by employing a special kind of gun for each nature of fire. A similar method might be adopted for infantry fire, the special rifles and ammunition being attached to and brought up with the siege trains.

the point aimed at on the intermediate object being such as will ensure the bullets passing over it and not being stopped by it; this is called *indirect aiming*. How to find the proper elevation for indirect aiming has been already given under the heading of "Indirect fire."

In some experiments on indirect aiming, carried out by the Siege Operations Committee, a pole (with a number on it) was set up for each man, or a strip of canvas was hung up on a supported wire about five and a half feet from the ground, with small numbers painted on it at intervals of about two feet along the top edge, and numbered so that each man might always know at what spot to aim; a plank supported on upright posts would do as well. The men were placed at such a distance in rear, that when lying down and aiming with certain sights at the marks, the elevation for the range was obtained and also the required direction. It was found that the longer the range the better were the results, as far as the intensity of fire on a given area was concerned, because the effect of small

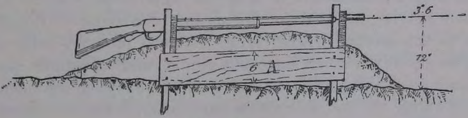


Fig. 15.*

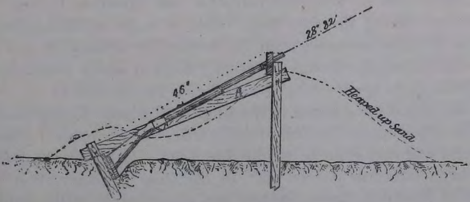


Fig. 16.*

errors of elevation tell less as the range increases. The general result, however, of the experiments showed that when the object to be hit can be seen direct aiming is the best, and that owing to the

* The rifles may be placed 30 inches apart, and the cross-pieces, marked A, should be 4 to 5 feet apart.

trouble of preparing for the indirect method it would seldom be applicable in the field.

Indirect aiming is only adapted for the case when a large area is to be covered with bullets, when the objects on it cannot be seen or only very indistinctly, or when the rifle is not sighted high enough for the range; hence its principal application is in siege warfare.

In some cases, as in a siege, when the slopes and form of the ground may be known or found out in firing at long ranges, the method of using rests for the rifles can be very well applied, as it increases the accuracy of a fire to a wonderful extent. The rests can be formed of rough boards, both notched as in *Fig.* 15, or one notched to take the rifles, and the other so fixed as to form a rest for the butts, as in *Fig.* 16. These rests should be fixed close to the surface of the ground, and weighted with earth, etc., to ensure steadiness. Up to the limits of the backsight, the rifles can be either laid directly on the object, or indirectly on an auxiliary point, or the elevation may be given by a clinometer; for ranges over the limit of the backsight, a clinometer or a special sight must be used. Effect of wind can be provided for by means of wedges. "Rough and ready as this method is, the results obtained promise, in the attack and defence of works, an extremely simple, and, as regards quantity of ammunition consumed, a cheap way of annoying the enemy, or even of aiding the fire of artillery, particularly when the object fired at cannot be directly seen." Such a method also is excellent for night firing (see p. 133), the elevation and direction having been ascertained during the day time. One or more elevations can be used as thought necessary, but to ensure the efficacy of any long range fire the range, should be exactly known, which is usually the case when such expedients as the above can be resorted to.

In the lectures laid down in the English Musketry Regulations, we find the following:—"In the attack or defence of fortified posts or positions, you may often be required to keep up a fire on a particular point after darkness has set in. In this case you may effect your object by planting, *during daylight*, two stout forked sticks firmly in the ground, so arranged as to relative height and direction (by the aid of sights properly adjusted), that when the rifle is laid on them it will have the necessary elevation and command the desired point; or the same object may be obtained by means of sandbags or large stones properly arranged.

"During the daytime, you may, by a somewhat similar expedient, keep up a continuous fire on bodies of the enemy's troops, who may from time to time be temporarily obscured by clouds of dust or smoke drifting across the front and concealing them. In this case, during a clear interval, having marked your own position, you should plant a single stick or rod in the ground a short distance in front of you, so that the top of it may be in line with your eye and the object at which you are firing;* you can then, when the enemy becomes obscured, keep up an efficient fire by aiming at the top of the stick."

NIGHT FIRING.

Experiments made by the Siege Operations Committee in 1879, in night firing with volleys (see p. 131) without the use of sights, which could not be seen, both on dark and moonlight nights with the rifle simply rested and otherwise, and the men in various attitudes, with bayonets fixed and off, showed excellent results up to 600 yards, but beyond this distance no certain results could be depended upon. As the sights could not be used, the elevation was judged, but as the dangerous zones up to 600 yards are very great, a great depth was swept from so many errors made in judging the elevation. The lying down position gave the best results and fixing the bayonet seemed no disadvantage, while it would give great moral support in war. Whitened fore and back-sights are good for night firing after dusk or darkness has set in; this is best and simplest obtained by tying white rags round the barrels over these sights.†

With artificial lights (as fires representing bivouac fires) and with the electric light, much the same results were got up to 600 yards.

Such night firing cannot be fully concentrated, as the object aimed at cannot properly be seen, and so it can only be frontal.

Night firing from rests, the rifles being laid during the day on the object, which might be any point over which the enemy must pass to reach the defenders' position, gave good results, and the remarks on firing from rests, given on p. 131, apply equally well to night firing.

From the deadliness of modern fire over ground that can be seen, many tacticians have come to the conclusion that in the future night attacks will have to be resorted to more than ever, so as to be able to approach the enemy to very close ranges under cover of darkness. In these night operations close order formations will play a great part, in order to maintain the necessary control over the men. The whole success of the attack depends on secrecy, surprise, and rapidity

* If the exact position of the eye is not fixed, two sticks or rods should be put down, the tops of which are both in the required line.

† When firing at night, the men should be taught to shut the eyes at the moment of firing, because if they do not do so, the sudden glare of the flash so dazzles them that they cannot see to fire again for a minute or so.

of action, while the security of the defence depends on early information secured by a good outpost service, on every man knowing and being able to rapidly take up his allotted position, and on the destruction, demoralization, or weakening of the enemy before he can close with the defenders. This latter point the defence can only effect by fire, and to fire with efficacy they should be able to see the enemy as soon as possible.

If the defenders should fear an attack, General Brialmont thinks that they should light fires of brushwood at nightfall on their front and flanks, and keep them up during the night. Behind these are placed the sentries and picquets, who are to show a lantern or to fire when the enemy appears. By the light of these bonfires,* the defending troops are to fire on the attacking columns.

In Afghanistan, at some of the posts on the line of communication, the superior slopes of the parapets were made parallel to, and nearly coincident with, the ground outside the fort, so that rifles rested on them would sweep the ground in front, without any aiming, in case of a night attack. At Tel-el-Kebir the superior slopes of the Egyptian entrenchments were horizontal, and this must have been one great cause of so little loss among our troops, as the bullets must have passed over their heads.

In the Franco-German and Russo-Turkish wars, several night attacks on both sides were repulsed by fire.

Long Range versus Short Range Fire.

A long controversy has been carried on on this subject, since the wars of 1870-71 and 1877-78, when long range fire of the French and Turks, even when defectively employed, produced such startling effects. But these effects were more due (1) to the dense formations used by the Prussians and Russians than to the mere intrinsic value of long range fire, and (2) to the defective employment of the short range fire of the French and Turks.

We know that troops will not alter their sights at ranges under 400 yards, and as the French and Turks aimed at the centre of the objectives, at closer ranges the fire passed over them. Also when

* General Brialmont says, these fires should be 2,000 yards to the front, but English experiments have shown that no reliable results can be got from night firing at over 600 yards. If the fires were at this latter distance, the sentries should be beyond them and hidden, because if the fires are within the line of sentries they could be better kept up, for if they are on or in front of the line of sentries, as General Brialmont suggests, the enemy might send out picked marksmen to shoot down any one attempting to feed the fires, and then wait until they went out before attacking.

firing down hill, which the French and Turks fighting defensive battles had to do, the fire is apt to go higher than when firing down hill. The Germans always aimed at the feet of their opponents, which kept their fire low and caused enormous execution at the short ranges.

Long range fire causes an increased expenditure of ammunition and hence must be cautiously used, and kept strictly under control; it is not so efficacious as properly executed short range fire; it tends to diminish the offensive spirit so essential to success; it is only efficacious against such large objectives as will rarely be seen on modern battle fields; and its extended use tends to make men shoot worse at the shorter and decisive ranges, from the fatigue and pain caused by the recoil and prolonged exertion of manipulating the rifle.

Hence the use of long range fire is only worth the increased expenditure of ammunition if there is an ample supply for the shorter ranges as well, if it can be easily replenished, if the ranges are known, if the atmospheric conditions and slopes of the ground are not too unfavourable, if the object fired at is of suitable dimensions, especially as regards depth, *if it is only employed by special troops*, and if it is kept well under control.

All Continental authorities have defined the terms "long ranges" and "short ranges," and we have just followed their example. The following numbers give the average numbers, while they suit the construction of the back-sight of the Martini-Henry rifle and the calculations given on pp. 84 and 85.

Short ranges from 0 to 400 yards.
Medium ranges from 400 to 800 yards.
Long ranges from 800 to 1400 yards.
Extreme ranges over 1400 yards.

Individual fire is to be used at the short ranges with one sight. Concentrated fire is to be used at greater ranges. Within the medium ranges two sights in combination are to be used under the conditions given on p. 112, and three sights in combination at the long ranges. The greater the range, the greater the concentration of rifles required to obtain the same effect.

Supply of Ammunition.

If short range fire only is used, 70 to 80 rounds per man are ample for an action, but if long range fire is employed as well, from 150 to 200 rounds are required by each man, the expenditure being regulated by a good fire direction, control and discipline (see p. 148).

All European armies echelon their ammunition in much the same manner, although the distribution of the ammunition in the different echelons is not the same. The battalion and other supplies form successive reserves of ammunition. Evidently no ammunition beyond that carried in the army corps ammunition columns can be immediately available on a battle field; and, indeed, only the leading echelons of these columns can be so. In the following table the ammunition supplies for replenishing the army corps columns, being a matter of ordinary supply, will not be considered. Calling the various echelons by the names of those corresponding to them in the English organisation, we see that the distribution of the ammunition, in the different European armies, is as follows:—

Table VI.

Method by which the Ammunition is carried.	Supply of Cartridges for Combatants.					Remarks.
	Germany.	France.	Austria-Hungary.	Russia.	England.	
By the men*	80	78	70	84	70	† A further supply of 11·5 rounds per man is carried in the company baggage wagons, but this is not available on the battle field.
In battalion wagons... ...	19·2†	18·1	52·5	60	30	
Total of first supply for fighting line	99·2‡	96·1	122·5	144	100	
In divisional or first line of ammunition columns	29·5	46·4	22·5	52	30	
General Total of supply for field of battle ..	128·7	142·5	145	196	130	
In army corps or second line of ammunition columns	29·5	33	6	13	30	

* Thus the weight of ammunition carried by the men of different nations are as follows:—

By the German soldier	7·392 lbs.
,, French ,, ...	7·515 ,,
,, Austrian ,, ...	6·545 ,,
,, Russian ,, ...	7·517 ,,
,, English ,, ...	7·438 ,,

‡ This is according to official numbers, but according to a new organization, not yet authorized, the German soldier is to carry 100 rounds on his person, and each battalion is to have two ammunition wagons, giving a further supply of 38·4 rounds per man for an effective of 1,000 men. This gives a total first supply of 138·4 rounds per man. Allowing for the usual sick and non-effectives before any fighting begins, this will give about 145 rounds per man effective.

These numbers are based on the battalion being at full strength, but if we consider the men absent in war time from sickness, wounds, or deaths, and that the cartridges of the killed and wounded should invariably be used, and that, even in the most hotly contested actions, all the troops present are rarely engaged, so that the supplies carried for these can if required be utilized by the troops firing, we find that with ordinary precautions for supplying the men, each man may be supposed to have from 120 to 150 rounds at his disposal in action, and have a further supply ready for him at the end of the day.

The officers commanding battalions are responsible for the ammunition carried by the men and in the battalion wagons; the artillery is responsible for the first and second lines of ammunition supplies; the depôt supplies in the English service are in the charge of the Ordnance Department.

There can be no doubt that if long range fire is not used, if a rigid fire discipline is maintained, and if the troops are only pushed forward within the medium zone, *after an efficient artillery preparation*, 70 to 80 rounds are sufficient to carry out an attack. But if long range fire is used with no fire discipline, and the troops are pushed forward to close ranges before the necessary artillery preparation is completed, then no limit can be put on the number of rounds that will be expended, but past experience shows that long range fire is only permissible when the immediate available supply of ammunition is *at least* equal to 120 rounds per man, and the means of replenishing the expended ammunition comparatively easy and ample.

In the English service there is no special or separate provision for the corps artillery, or even for the divisional artillery, such as there is abroad; but as there are three divisions in an English army corps, each divisional ammunition column carries one-third of the artillery supplies for the corps artillery in addition to those for the divisional artillery. This is a very defective arrangement, because if one division is detached with its ammunition column, it takes with it one-third of the supplies for the corps artillery which remains with the other two divisions. The French, German, or Austrian subdivision, which allots a distinct section or unit to the divisional infantry, to the divisional artillery, and to the corps artillery, is much to be preferred.

With regard to the mode of conveying the ammunition, whether on wheels or on pack animals, it is a question to be decided by common sense and the nature of the roads. If the roads are good enough, wheeled transport is a saving of horses, attendants, food, etc., because a two-horsed cart carries at least as much as eight pack animals. If the roads are bad and carts cannot travel, pack animals must be used.

Where small forces are engaged, as in our savage wars, they cannot protect the zone of territory in rear for any distance, and hence the ammunition supplies, beyond those of the battalion, must be kept close to the force. They are usually called the "second reserve of ammunition," the immediate battalion supply being designated the "first reserve of ammunition."

The following are the different means available to make the supply of ammunition on the battle field as perfect as possible.

1. The personal necessaries in a soldier's valise should be reduced to a minimum, while the number of cartridges which he carries should be increased to 100 rounds, and an extra haversack and ample pockets (in his coat and trousers) should be given him, to enable him to do this, and to receive a further supply of 50 or more rounds on going into action. The ammunition of the dead and wounded is also to be made use of.

2. The supplying of ammunition should precede the attack, as the service only can be carried out under exceptional circumstances during a close fight. Every pause in the fight should be fully made use of to replenish the supply of the men firing.

3. The load of the foot soldier should be lightened to the extreme limit possible, but it should be absolutely forbidden to put the valises on the ground previous to an attack, unless the cartridges have been first taken from them. The cartridges in the pouches to be used last.

4. There should be a universal pattern infantry ammunition cart or wagon for the battalions and divisional ammunition columns, so that they may be interchangeable.

5. If they are of the same nature, the infantry carts or wagons should either be of a different pattern or shape, or be painted a different colour to those of the artillery (or have bands of different bright colors on them) to distinguish them, so as to facilitate the supply.

6. The battalion and divisional ammunition carts or wagons need not have the name of the corps or column painted on them, so that there need not be any necessity to return them to their original owners after an action.

7. Flags and lamps of different colors are required, to show the positions of the battalion carts or wagons, and of the infantry and artillery sections of the ammunition columns. These flags in an action should be placed at some distance to one side of the supply centres that they mark.

8. The cartridges should be solid drawn, and made up in packets of five; they can then be kept in canvas bags with handles, each containing 250 rounds, or 50 packets of five each. Wooden, tin, or zinc-lined boxes may hold four of such bags each or 1,000 rounds, and two boxes would form a convenient load for pack transport; the cover of the boxes should be very easily opened, without the assistance of instruments.

9. Special canvas bags should be carried on every battalion wagon or cart, and on a certain number of men per company, to enable the ammunition supply service to be carried out. Supplementary stretchers, capable of conversion into hand barrows, might also be carried on the wagons or carts for facilitating the distribution of ammunition.

10. In each battalion a non-commissioned officer should be trained for the ammunition service, also some men of each company to act as drivers of the wagons, and others to carry out the duties of carriers, loaders, etc., and thus to create a true battalion fighting train.

11. The supply from the battalion carts or wagons to the combatants to be carried out as much as possible from the rear by men taken from the supports and reserves.

12. Constant connection to be established between the battalion and divisional reserves, by mounted men trained to this duty.

13. In the case of a desperate fight, small depôts of ammunition should be made in rear of the fighting lines.

14. Immediate replenishing of every empty cart or wagon by the divisional and army corps ammunition columns, by an exchange of ammunition, or if circumstances require it, by an exchange of wagons or carts; these latter to be brought up to the point required.

15. To enable supply to be carried out by pack animals, on favorable opportunities, either to provide special pack animals for the purpose, or to give some of the draught horses pack saddles (or riding saddles strong enough for pack purposes); a pair of canvas saddlebags would then be required for each pack animal.

16. During the marches which precede an action that is imminent, the divisional reserve ought to hand over one or two wagons, or an equivalent number of carts, to each battalion destined to take part in

the preparation of the fight. The commander will base his orders for the distribution of these wagons or carts on the distribution of the *rôles* of preparation and execution among the attacking troops. The advance guard should also have a certain proportion of extra ammunition carts or wagons attached to them.

17. Any *engaged* troops should be allowed to draw on the battalion reserves of any battalion for ammunition. A signed requisition should not be required, but a statement as to the amount drawn, the hour, and by whom drawn, should be written and signed while the ammunition is being served out, to act as a check both on the amount of ammunition left in the battalion reserves and upon the corps who have fired away too much.

From Table VI., on p. 136, and the foot-note attached to it, we see that, on the battle-field, English troops would have a smaller total supply of rifle ammunition than any other army. The Author thinks that by reducing the contents of the valise, each infantry soldier could carry 100 rounds; engineers 50 rounds; and non-commissioned officers only 20 rounds, as these latter should really look after the men and rarely fire themselves. The battalion carts and the divisional and army corps ammunition columns should each carry 40 rounds per man for units at war strength. This would give a nominal total of 180 rounds per rifle on the battle-field, and a real one of over 200 rounds per rifle, if the non-effectives are not counted. The ammunition columns should further be divided into distinct sections for the infantry and for the divisional and corps artillery. The want of this latter sub-division is a great defect in our service.

Before concluding this chapter we must refer to the question of using carts or wagons for carrying the battalion and divisional ammunition reserves. England makes use of two-wheeled carts, while Germany, France, Austria-Hungary, and Russia use wagons with limbers, &c., very like those used by artillery.

Such wagons *may* get mixed up with those of the artillery unless distinguished by colour, but these colours may be easily obliterated by the rough usage and exposure of a campaign, and being special wagons they require special manufacture, and cannot be used for any other purpose.

England and Russia* have both found two-wheeled carts to answer

* The Russians in 1880 experimented with different kinds of ammunition carts and wagons, and came to the conclusion that two-wheeled carts were the best as regards lightness, mobility, and capability of surmounting obstacles.

every purpose. They require more careful loading than wagons, but they cannot be mistaken for the artillery ammunition wagons, and are more easily replaced by local means. They must be strongly made so as to be capable of being taken across country.

With regard to the form of cart, it is objectionable to use one, as we do, that is of a special character, and cannot be used for any other purpose. The pattern of Maltese cart, to be seen in the Royal Carriage Department in Woolwich Arsenal, and which is known as Mark III., is much better suited for the purpose than the present small arm cart. It has a platform 5 ft. 9 in. long by 4 ft. broad, and weighs 6 cwt. 1 qr. 14 lbs., while the present small arm cart weighs $8\frac{1}{2}$ cwt. when empty, and 20 cwt. when full, showing a saving of over two cwt. per cart, even including a tarpaulin to cover the ammunition when carried in a Maltese cart. This cart can be easily drawn by two horses, and has the great advantage that when in camp the ammunition can be taken out and the cart used for bringing food from the Commissariat stores, water, wood, forage, etc., or for any other battalion administrative purposes. It is fitted with slats, which can be attached to the shafts to enable it to be used for hand draught. This cart is a very simple one, and can be made and repaired anywhere, and if necessary in difficult country, three horses could be attached to it abreast, or in unicorn fashion.

In the English service it would be far better to have four such carts per battalion or 1 per double company, and as each cart can carry 9,600 rounds (the weight of which, including boxes, is 1,268 lbs.), this would raise the battalion ammunition supply to 40 rounds per man.

UNCONTROLLED AND CONTROLLED FIRE.

There are two methods of allowing men to fire :

1. *Uncontrolled* or *independent fire*,* in which each man fires at his own convenience and judgment as to range and objective.

2. *Controlled* or *concentrated fire*, † in which the independency of the fire of the individual men is controlled and directed according to the will of their commander.

Controlled fire can only be executed when the men are collected into organized tactical groups or massed bodies, which are then used as "units of fire," because, under an enemy's fire, one leader alone

* The word "individual" is purposely not used here, as "individual firing" does not necessarily mean "uncontrolled firing" as "independent firing" does.

† *Concentration* of fire necessitates *control*.

cannot control a large number of individual men, although he can a number of organized groups.

Uncontrolled individual fire is naturally independent fire, and anything *independent* should be avoided as much as possible in war, as it is not likely, if uncontrolled, to work for the mutual good of the whole. As General Skobeleff said in one of his famous orders in the Geok-Tepe campaign, "Mutual action always has been, and always will be, the secret of victory."

Both uncontrolled and controlled fire have their theoretical advantages and disadvantages, but practically, it has been found that uncontrolled fire is very pernicious, and is conducive to great waste of ammunition, and what is far worse, to great loss of moral force in the men using it. The advantages and disadvantages of the two kinds of fire are as follows :—

Advantages of Uncontrolled Fire.

1. It allows the soldier the greatest independence to fire when and at what he likes. (A doubtful advantage when the good of the whole should always be thought of.)

2. It gives a quicker and more continuous fire than controlled fire, which must have pauses for instructions and orders.

3. In certain situations, as in cases of extreme danger and excitement, it applies itself better to the moral state of the soldier, because it does not require a continued attention to the commands of the leaders, as a controlled fire does.

Disadvantages of Uncontrolled Fire.

1. When once begun, especially when near the enemy, it can neither be regulated nor moderated, and degenerates into a rapid and wild fire.

2. From not being able either to regulate or moderate it, it leads to an excessive consumption, and therefore waste, of ammunition, and to disorder.

3. There is no check as to what the men are firing at, or if they are using the proper sights, or even that they are aiming.

4. It soon produces in front of the men such a thick smoke that the object fired at is completely hidden—a disadvantage which does not show itself to the same degree in controlled fire.

5. It presents to a commander such great difficulties in controlling

both the fire and the men, that it almost renders any required offensive advance impossible which is not already in operation when the uncontrolled fire begins.

6. It has a very bad effect on the moral spirit of the men, as it tends to increase the excitement by causing an impression that danger is near, and as the ammunition decreases, so does the courage of the men engaged, unless fresh troops are forthcoming at this moment.

7. The fire cannot be readily directed from one object to another, or the sights altered.

8. It is the least terrifying kind of fire to an enemy, from its inaccuracy, especially as the range increases.

9. It is almost always frontal and unconcentrated.

Generally, once an uncontrolled fire is allowed to begin, especially if the enemy is near at hand and the excitement great, it will continue unchecked until the last round has been spent, from the natural tendency or inclination of the men to fire as hard as they can to keep their spirits up, so as to enable them to stand the intense mental strain of the moment. In very heavy firing neither bugle, whistle, or voice can be heard to put a stop to it. Therefore this uncontrolled fire should be used as rarely as possible, and to practice it at drill is considered, by some writers, not only needless but positively harmful. At short ranges, in close contact with the enemy, any controlled fire will of itself degenerate into a rapid uncontrolled fire, the men will no longer pay any attention to orders for control, and the pauses will disappear. There is no need to order independent or uncontrolled fire in such cases, for no prohibition will prevent it.

Advantages of Controlled Fire.

1. Not a round of ammunition can be fired without orders.

2. It gives the means of regulating the intensity of the fire by the rapidity with which the words of command are given.

3. It gives the means of seeing that all the rifles are directed on the chosen spot.

4. The fire can be stopped to allow the smoke to clear off when it gets too thick.

5. The pauses in the fire can be as long as the commander pleases.

6. The pauses enable orders to be passed down the line as to what is to be fired at, when to cease fire, when to advance, etc., and has a quieting effect upon the men when they are tending to get out of hand.

7. It permits the commander to control the effects of the fire, according to the results he sees produced.

8. It enables the fire to be stopped at will, on an order, which permits of an immediate offensive advance from the defensive or halt.

9. The fire can be rapidly directed from one object to another, such as to oppose an unexpected charge of cavalry.

10. It allows a change of elevation to be made at any instant.

11. It allows of a use of combined sights when means of ascertaining the distance accurately are wanting.

12. It allows of seeing whether the men are aiming or firing wildly.

13. It gives better results at all ranges, because, if men are left to themselves, they always fire at the centre of the objective, or at a prominent one only ; with a controlled fire, it can be directed successfully against all parts of the enemy's fire.

14. It has a sudden and therefore offensive character.

15. It has a very terrifying effect on the enemy when the range is known and the fire is well delivered, as it suddenly pours in at once a searching concentrated mass of bullets at one spot, while in uncontrolled fire the fire cannot be concentrated, and so the bullets fall here and there.

16. It shakes the moral force of the enemy by the sudden loss of a number of men.

Although the following remark of General Brialmont was made with reference to formations, yet it can be equally well applied to the relative moral effects of controlled and uncontrolled firing. "Men in column are more powerfully impressed by losses than men in line, especially if they halt to fire. This is because the men killed or wounded in a deep mass are seen by a greater number of soldiers than the same number of killed and wounded men in a thin line. This difference of moral effect is especially felt when infantry is exposed to artillery fire." General Brialmont might also have added, "to a concentrated infantry fire." A given number of men falling at the same instant will produce a greater demoralising effect on the remainder of the men than an equal number of men falling here and there, singly or in twos and threes.

Disadvantages of Controlled Fire.

1. The greatest rapidity of fire cannot be obtained from it, from its requiring pauses for instructions to be given, but this rapidity of

fire is rarely wanted until the closest ranges have been reached, while it soon causes such a thick cloud of smoke that the object cannot be seen, which must cause a great waste of ammunition. This extreme rapidity of fire only takes place when it becomes uncontrolled from the proximity of the enemy, and when the objective therefore is near enough to be hit by being in the dangerous zone of the rifle when the latter is placed parallel to the ground which is the only rule for aiming that can be followed in a thick smoke.

2. It is unsuitable to certain demoralising situations, as for example, the very close approach of an enemy which keenly impresses a soldier and makes him inattentive to the voice of his commander.

Controlled firing is only possible when the troops have sufficient calmness and presence of mind to listen to orders. In European warfare this is rarely possible at the short ranges, except on the defensive, when the firing line is sheltered by natural obstacles or by entrenchments.

From the examination of the properties of controlled and uncontrolled firing, we find that a controlled fire unites the greatest number of advantages, and ought, therefore, to be preferred for all cases for which it is suitable. Therefore uncontrolled fire should only be used where a controlled fire is not possible, viz., when in very close proximity with an enemy.

Whatever the disadvantages of controlled fire may be, they will be amply compensated for by the control maintained over the men, by the certainty that ammunition will not be wasted, that the sights will be properly adjusted, and that the fire is directed where required.

"Fire can be executed in two ways: by command or independently. Experiments have been made with both alternately. In war it is very important not to waste ammunition uselessly ; the fire ought to cease immediately that the objective disappears, or when it offers too small a surface ; the officers ought therefore to be masters of it, and, in this point of view, fire by command has the preference."—(C.C.J.)

"Controlled fire preserves us from the thoughtless firing of a soldier who believes he has acquitted his conscience by having fired off all his cartridges, without considering the *nil* results which arise from such a badly organized fire."—(Okounef).

"Controlled fire renders a commander capable of carrying forward his men at the exact moment he judges opportune ; he holds them better in hand, so to say ; controlled fire produces on the enemy an overwhelming moral effect, because it presents to his mind a feeling of order and consequently of an organized force; it prevents waste of ammunition in a futile firing; in a word, when properly applied, it should absolutely prevent the success of an offensive movement on the part of the enemy."—(Girard.)

"In an uncontrolled fire soldiers do not adjust their sights properly; they fire quickly, the smoke prevents them from seeing before them, the noise of the firing drowns the voices of the leaders and even the sound of the bugles, and thus the men continue to uselessly waste their cartridges."—(D'Azémar.)

The Italian regulations say, "The maximum effect of fire can only be obtained so long as the fire can be concentrated on the point which seems to be the most important, and in the shortest time possible." This can only be done by means of a fire perfectly under control.

Every cartridge may be life or death to a man, so he should never waste a round. He should never fire where he cannot see anything to fire at, but he may fire at smoke, and ought to do so, to intimidate the firer there, and so demoralize him, while he may even hit him. *Victory is not decided by mere loss of numbers only, but it is gained by that side which can first intimidate or demoralise its opponent.*

"The Germans have very strong ideas on the character which ought to be given to fire in battle. They do not hold with a slow continuous, progressive fire; in their opinion, the action of fire should in all circumstances be sudden, unexpected, and powerful, in order to present an offensive character. Thus, this action can only make itself felt during successive very short intervals, separated by a pause during which order and calmness are re-established, smoke is allowed to dissipate, and orders relative to the objectives to be fired at, the elevations to be used, are given. The effects of suddenness and power of the fire obtained by means of such an intermittent fire, apply equally well to a decisive or to a demonstrative action (such as true or false, or principal or secondary attacks); a continuous fire has not the same effect. Also, an intermittent fire appears further destined to be retained in the future from necessity, because it is the only kind possible and admissible with repeating rifles, which are likely to become the armament of infantry."

Further, an intermittent fire allows of efficaciously maintaining fire discipline, and of checking the troops who have a tendency to prematurely expend their ammunition and to get out of hand. *The economy and the regulated expenditure of cartridges is, and will remain, a vital question in the tactics of modern fire.*

The regular pauses of controlled firing should be obtained by the fire of large units ceasing, as a whole, for a sufficient time. If the pauses are only obtained by groups, one of these will finish before another and perhaps begin again, so that no real pause in the firing line will occur for orders to be transmitted, or to allow the smoke to dissipate, and it will have all the appearance to the enemy of a continuous fire, losing thereby the moral effect of suddenness.

We have said that uncontrolled fire should be reserved for very close ranges in which aiming is not essential, or indeed is impossible from the smoke, which always hangs about a heavy independent fire, but which only requires that the rifle should be fired parallel to the ground.

Therefore, up to 400 yards, or as near as we can get to the enemy, we should employ controlled fire, which enables us to assume the offensive readily, to control the fire, and to hold the men in hand, while it has a high moral effect on one's own men, and a bad one, if well directed, on the enemy. Having got as close as possible, say 400 yards or even nearer, the strain becomes very great on the men, and we cannot prevent a rapid uncontrolled fire. Any hope of forcing the men forward now against their instincts will be hopeless. Now comes a period of the most rapid fire. This will be the critical moment of the fight; soon a desire or panic to rush forwards or backwards will seize the men; if the enemy is demoralized, and consequently relaxes his fire, or retires, then the men will rush forward to victory; but if the enemy is not shaken, and still pours in a deadly steady fire, then the men must recoil before it with terrible slaughter. A rapid short range fire is not an accurate individual fire, *but depends for its efficacy on the grazing power of the fire of the mass of troops.* The French musketry regulations say that "a rapid fire, executed at from 220 to 330 yards, only owes its efficacy to the flatness of the trajectories. One is forcibly led to use it when the moment of the final crisis arrives. Its duration will be very short, and this crisis will be followed by the solution." A rapid fire is most fatiguing to the men, and cannot possibly be maintained long.

Of course we have here considered the soldier as pitted against an enemy as well armed as himself, and equally skilled in the use of the weapon. Against an inferior fire or enemy, a controlled fire will be just as effective at these short ranges, and may be feasible to maintain, because, as the men will not be so excited or demoralized by losses, a greater control over the fire will be possible. But at all times we must remember that so many causes tend to make uncontrolled fire inaccurate, viz., hasty firing, individual faulty appreciation of distance, badly adjusted sights, and thus waste of ammunition, smoke, and the tendency that such a fire has to weaken the moral force of the men, that we ought to try and keep it for the shortest ranges only. As has been pointed out before, the longer the range, the more necessary it is to concentrate the fire so as to increase the chance of hitting, and also the longer the range, the larger should be the number of men firing at the same mark. Controlled fire allows a deliberate aim to be taken, and a deliberate and far more accurate estimation of range; it allows of watching the men adjust their sights, and of controlling the expenditure of ammunition, there is much less smoke with it than in uncontrolled firing, while this smoke clears away quicker; it tends to increase the moral force of the men, besides which, it does not form a continuous line of smoke, constantly showing one's position to the enemy. Thus in every case controlled firing is best, and should be maintained until the enemy is so close as to render it impossible to be carried out from the excitement and tension of the men's minds, and then a rapid uncontrolled fire must be permitted; in fact it cannot be stopped, for the men will take to it of their own accord. The worse the enemy, the less will this distance be.

Thus controlled firing is essential because it is of the greatest importance that a commander should not cease for a single instant, if possible, to have his men perfectly in hand, if he wishes for success. This can only be done by controlled firing, as an uncontrolled fire, unless in exceptional cases, reduces the power of control over the men to a minimum.

"Thus, the education of the soldier ought to be directed towards a severe fire discipline, so that a commander may, in the middle of a combat, obtain every advantage from the rifle, and be able to pass suddenly from the defensive to the offensive when the opportune moment, always short in war, presents itself."

FIRE DISCIPLINE AND THE CONTROL AND DIRECTION OF FIRE.—FIRE UNITS OR GROUPS.

Now since infantry in action acts almost exclusively by fire, it can only obtain a superiority over an enemy by means of a superiority of fire. This superiority is gained either by a numerical superiority, by a greater efficacy of fire, or its greater rapidity, combined in each case with a great consumption of ammunition and suitable formations of small depth to prevent losses from the enemy's fire. The general principles of directing infantry fire, are given on pp. 307-308 of the latest edition of the *Field Exercises for Infantry*.

The direction of the fire means (1) the determination of the kind of fire to be used; (2) the advisability of allowing men to fire while in movement or not; (3) the choice of the moment when bayonets should be fixed; (4) the choice of the attitude to be taken up by the men firing; (5) the selection and allotment, amongst the body of troops firing, of the objects to be fired on; (6) the determination of the range and choice of sights to be used; (7) the determination of the moment of opening fire,* the estimation of the number of cartridges to be used to attain a definite object, and the consideration whether the existing phase of the fight, as well as the available supply of ammunition, and the facility of replenishing it, will justify such a consumption; (8) the determination of the force required in the firing line, in order that the number of cartridges deemed necessary may be fired in the desired time; and (9) finally, the supply of fresh ammunition and means of providing it.

The control or *command of the firing* consists in the carrying out of the above orders, that is, in ordering the elevation, the objective to fire at, the number of rounds to be fired, and the kind of fire to be employed, in seeing these orders obeyed, and in watching that the men take careful aim with the required elevation, and on the desired object.

The direction and control of fire are included under the name of *fire tactics.*

Fire discipline, or *the execution of the fire*, may be defined as nothing but the unhesitating habit, developed in the men by instruction and training, of commencing, or ceasing, or relaxing the fire, or of concentrating it upon a defined object, instead of directing it at a mark chosen by each man, all in obedience to the deliberate will of the commander. *No firing should ever be permitted without orders, and it should cease immediately the command is given for it to cease.*

The Italian regulations say that "In order to obtain the maximum effect from infantry fire, the indispensable conditions are:—A rigorous fire discipline on the part of the troops who execute it, and an intelligent direction on the part of the leaders who command it."

The Germans, who have perhaps studied this question most deeply,

* This is more with reference to the period before the actual offensive attack takes place.

are unanimous in declaring that fire discipline must be obtained by the moral ascendency of the leaders over their men; but they own, that even with this ascendency the control of the fire can only be maintained up to a certain point.

The most perfect supervision will lead to no result unless it is supplemented by the most stringent fire discipline, and it cannot be too strongly impressed that *it is only when every soldier has been well practised in this fire discipline that the full effect of modern rifles can be obtained.*

When direction and control are no longer exercised, fire must become irregular, and therefore, *as a principle,* the company and sectional commanders must endeavour to preserve the direction of the fire as long as possible, even at the shortest ranges.

"To keep their men in hand ought therefore to be the constant and principal preoccupation of every company officer in all peace exercises; they ought to try and maintain the direction of the fire as long as possible, even when their men have entered into the zone of short ranges. If they know how to do this, if they succeed in time of peace to inculcate into their men this fixed conviction of 'not to fire a single shot without the approval of the nearest officer,' then they may hope to obtain in the field such a fire discipline as will be fruitful of great results."

Now let us deal in detail with the first eight different parts of the duty of direction, mentioned on page 149. The ninth heading, on the supply of ammunition, has been fully dealt with on p. 135, and will not be referred to again.

1. The kind of Fire to be used.

Now, as we have seen, a commander can choose between two kinds of fire—

(i.) Independent or uncontrolled fire; and

(ii.) Concentrated or controlled fire.

But as fire discipline and direction entirely depend on control, *independent fire,* from what has already been said about it on p. 142, is only permissible when these are not possible. The effect of such a fire is usually very weak, except at the very shortest ranges (*i.e.*, under 400 yards), as it is made up by the frontal, and therefore by the unconcentrated, fire of individual men acting independently, which is only effective up to such ranges, and if these men are excited or out of hand from the effects of the enemy's fire, it becomes wild and cannot be stopped until the last round is expended. It should only be allowed at the shortest ranges, where a single man may hope to hit the object he aims at while firing at his own discretion and freely choosing his own objective.

The controlled fire of men may be executed in two ways:—

(*a*) By the *individual fire of the mass*, or *mass firing*,* as it will be called, in which each man fires the number of rounds ordered at his own convenience at the object ordered, and with the sight or sights ordered, thereby causing, while the fire lasts, a *continuous* rain of projectiles to be concentrated on the object.

(*b*) By *volley firing*, in which all the men fire together simultaneously by word of command at the object, and with the sight or sights ordered, thereby causing a concentrated mass of projectiles to be suddenly projected at the same instant, but at *intervals*, on the object fired at.

Both mass and volley firing can be carried out by closed or extended bodies of troops, but volleys require considerable control over the men, and can therefore only be executed in action by extended men at some distance from the enemy, when the required control is possible.

In order to control infantry fire, and to allow it to be effective, there must be pauses in it, during which the smoke is allowed to clear away, the effect of the fire watched, and orders and information transmitted as to the object to be fired at, the ranges and sights to be used, etc., etc.

The Germans and French lay great stress on these pauses for another reason. They deprecate a slow continuous fire for infantry because it causes too great an expenditure of ammunition, and gives none of the advantage gained by the moral effect caused by sudden losses. They say that the action of fire should be sudden, unexpected, and powerful, so as to have an offensive aspect, and that this action should be felt only during successive very short periods divided by pauses which are utilised as above stated. The French regulations say that, "The suddenness of fire is one of the principal conditions of its efficacy. The moral influence of a material result is greater as this result is obtained in a shorter time."

This sudden and powerful action can only be obtained with troops perfectly trained in fire discipline, and when the direction and control of the fire have been thoroughly practised. This kind of fire is con-

* This fire is generally called "individual fire" or "fire of skirmishers" in the regulations of foreign armies, but these names are not used here lest confusion might arise from a different meaning having already been attached to them in previous pages.

sidered to be more impressive, to require less ammunition, in order to obtain a certain result, and to gain a given result in less time than a sustained slow and continuous fire. The Germans always endeavour to get a maximum effect in a minimum of time. "One ought to try, as regards the general direction of the fire, to concentrate the fire on the same important point and during a very short time." It may be remarked that the Austrians advocate a sustained slow fire.

The French say, further, that a slow fire executed by isolated men has no useful effect; it presents, moreover, the inconvenience of retarding the advance.

Although the German regulations lay great stress on the suddenness of fire, and lay down that men advancing under fire are to do so by successive advances of fractions during each of which all fire is to cease and after which the sudden fire is to open, yet their practice differs from this. For some years past their infantry has been taught to deliver while advancing a mass fire of a given stated number of rounds, by each man in succession of a group or other named unit running out to the front, halting, kneeling down and firing, and then waiting for the line to come up to advance again with it and to await his turn. They trust to the discipline and training of their men to effect this without confusion.* They consider such a method more adapted to keeping up the moral force of the men, who will advance more readily when firing, as it helps to keep up their spirits and tends to demoralize the enemy. These remarks do not apply to the method of advance by short rapid rushes at the close ranges, because these rushes are made at full speed to avoid loss, and therefore no firing can take place while they are being executed.

In volley firing a pause is obtained at the end of each volley, but in mass firing the only way to obtain the pauses, and to prevent the fire escaping from control and degenerating into an independent fire, is to limit the number of rounds to be fired by each man, who must then cease firing. *The number stated should not exceed three*, as men under fire, especially if excited, cannot be expected to keep count of a greater number.

Advantages of Mass Firing as compared with Volley Firing.

1. Each man can fire at his own convenience better.
2. It can be used at shorter ranges.

* It would be preferable to make the men fire thus in groups (see p. 171). Each group would run out to the front under its leader and halt for the line to come up. Control over the men would be better kept up by such means.

3. It can be used at any range, by troops in any formation, and by any number of men.

4. It is more suited to moments of great moral strain.

5. A greater number of rounds can be fired in a given time from the fewer pauses.

6. It is better suited to an extended firing line under a single leader.

Disadvantages of Mass Firing as compared with Volley Firing.

1. Unless carefully looked after, and controlled, it may degenerate into uncontrolled fire, as it will do in any case at the short ranges.

2. Its moral effect on the enemy is not so great.

3. The regulation and alteration of sights is not quite so easily carried out.

4. The control over the men is not so great.

5. Its effects cannot be so easily observed.

6. The strike of the bullets can hardly ever be seen for correcting the sights.

Advantages of Volley Firing as compared with Mass Firing.

1. It has a greater moral effect on the enemy.

2. It enables greater control to be maintained over the men from the greater number of pauses.

3. It is not so likely to degenerate into uncontrolled fire.

4. The regulation and alteration of sights is more readily effected.

5. Its effects can be more easily observed.

6. The strike of the bullets can be better seen to correct the sighting.

7. It gives a more certain method of directing the whole fire.

8. It is the best kind of fire for repelling night attacks and for use against cavalry.

Disadvantages of Volley Firing as compared with Mass Firing.

1. It is not so well suited to extended formations, and can then only be used by comparatively small bodies of men.

2. It is not so well adapted to all the circumstances of war.

3. It is not so suited to moments of great moral strain.

4. The men cannot fire so well at their own convenience.

5. It is not suited to very small or very large bodies of men.

6. It is not suited to short ranges, as it requires greater control over the men.

7. From the greater number of pauses, less ammunition can be fired in a given time.

A well adjusted mass fire is considered by the French and Germans to be slightly more accurate for a given number of rounds, independently of time, than volleys, but the difference at the best, and on measured ranges, is only slight, and in the less favorable circumstances in the field they may, for all practical purposes, be considered of equal accuracy. But, in a given time, mass firing gives an undoubtedly better result or useful effect (see p. 153).

On page 142, we saw that a more rapid and less accurate fire, could within certain limits, give a greater useful effect than a slower and more accurate fire, though only of course at the expense of wasting a considerable amount of ammunition.

If aim is really taken by the men, mass firing gives rather better results, but volley firing is the only real means of insuring that the men do take aim.

The Italian regulations say that with mass firing "it is difficult to regulate the fire and to maintain fire discipline. Mass firing, without *an iron discipline*, easily degenerates into a quick and unregulated fire."

Volleys are the only certain means of directing the whole fire on the object chosen by the leader, and we must remember that the one essential condition for efficacy of fire, over 400 yards, is its concentration on particular spots, and not to allow of its being scattered on a wide front. In volley firing the point to be fired at is indicated, the men only load and fire by word of command, the consumption of ammunition is strictly regulated, and all waste is reduced to a minimum. But volley firing requires great coolness on the part of the leader, as well as the troops, and therefore it can only be employed at a certain distance from the enemy, unless the troops are covered from his view and fire. The leaders must be very careful that the volleys are fired together, for if some men are allowed to fire before or after the others, independent firing will probably ensue. Unless troops are thoroughly well trained and disciplined, any kind of controlled fire cannot be maintained in action, but will soon degenerate into independent fire.

In repelling night attacks, when troops are so liable to get out of hand from not being able to see what is going on, volleys are the only kind of fire that is advisable to employ to prevent a rapid, wild, independent fire taking place.

Another advantage of volleys over mass and independent fire is for use against a body of troops in motion, especially cavalry. Then volleys have a great superiority, in allowing an alteration of sights.

Cavalry charge at the rate of 400 yards a minute, during which time two rounds can be fired with accuracy. Thus, if alternate units fire, one may use an elevation 200 yards less than the other.* Men would not thus regulate their sights in any other kind of fire. When cavalry are within 500 yards, the men cannot be relied on any longer to fire volleys, and will fire independently, which does not matter at this close range, provided they will cease firing when necessary.

All the advantages of volley firing, however, must not be expected in war; still they should be aimed at as far as possible; and it is none the less certain that the more troops have been trained in time of peace to pay attention to the slightest sign or gesture of their leaders, the greater will be the discipline and power of control over them in the fight. It is a matter of peace training and constant practice. *Troops which have not been broken into it, will not possess fire discipline, however much they may have been disciplined in other respects.*

From the accuracy and power of artillery, men have to extend in action at longer ranges than infantry fire would ever be opened at. This extension is bad for executing the volleys required to give an effective concentrated fire, even at ranges under 1,200 yards, if attempted with large bodies of men; but if it is decided to open fire at ranges over 800 yards, it is undoubtedly best to employ volleys from small bodies of men, from the economy of expenditure, the power of regulating and watching the fire, the moral force imparted by a feeling of order, and the command over the men that it gives. Hence the line of men required to give the requisite amount of concentrated fire must be divided into "*fire units*" (see p. 171), and the commander of each fire unit receives the order for the direction of the fire, which he communicates to the men, and sees carried out. As we approach nearer the enemy, and his fire gets more accurate, losses occur, and the control becomes more difficult; but, if any abnormal mixing of units has not yet taken place, then by a judicious reinforcing, by pushing complete units into gaps, instead of directly to the front, volleys can and should be still continued as long as possible, by means of small "fire units," especially if the men are inclined to get out of hand. But if an irregular intermixture of units has taken place, or when the control for volleys gets too difficult, mass firing must be resorted to, and every effort made to maintain it until it develops of its own accord into a rapid independent or uncontrolled fire, in which the men will no longer pay attention to the directions

* If cavalry are trotting, allow only 100 yards difference in elevation.

of their leaders limiting the number of rounds to be fired, thus causing the pauses to disappear; after which, the personal example or influence of the leaders is the only controlling effect on the men, and then a few minutes will decide the action one way or the other. If the enemy is demoralised, from having suffered, materially and morally, from a sufficiently accurate and prolonged artillery preparation, and from the intense rifle fire that has been poured in on him, his fire will slacken, and the attack will rush forward to victory; if not, the attack will be driven back, which retreat, if unsupported, and if followed up by the defence, will be most disastrous to the assailants. The mass fire can be taken up by the same fire units, when volleys are no longer possible. Before joining the firing line, all leaders must be informed as to the direction of the attack and of the fire, and men who get separated from their groups ought, from previous instruction, practice and discipline, to join themselves to the nearest leader for the purpose of concentration of fire. Independent fire will dictate its own time and range; the greater the discipline, the longer will this undesired period be delayed.

The properties of volley firing are so seductive, in spite of their being harder to execute than mass and independent firing, that they have led to their frequent use in peace exercises at shorter ranges than practicable in war. Volleys cannot be enforced within range of effective individual firing (*i.e.*, 400 yards at the most), as at that range they are, as a rule, quite impracticable in the field when opposed to civilized troops, because the noise and excitement of battle disconcert the troops, orders are no longer distinctly heard, or even punctually obeyed, every man seeks to obtain from the ground a shelter from the enemy's fire, the group units get involuntarily broken up, and independent firing will, if care is not taken, supplant that of volleys, without any human power being able to prevent it. It belongs to the leaders to foresee this moment; recognizing it in time, they will themselves order mass firing to commence before independent firing commences of itself; they can then perhaps preserve the direction of fire, limit the number of cartridges to be expended, by naming the number of rounds to be fired at each pause, and make the pauses sufficiently long to allow the smoke to disappear and for the sights to be rectified. Even though these results may not be fully obtained in war, yet they should always be aimed at.

Volleys can only be used at close ranges, even on the defensive, by troops who are well in hand, and who have been well trained and possess a high degree of fire discipline. Thus, they are not so likely to succeed with young troops, or even with old soldiers, who are fatigued or excited.

Mass firing and independent firing are, therefore, as a general rule, the only kinds of firing possible at the shorter ranges, when all efforts must be directed to prevent its deviating from the original direction, and to prevent its degenerating into a wild irregular fire, so wasteful of ammunition at a time when it cannot be replaced.

The value of volleys, as compared with mass firing, is undoubtedly more one of moral than material effect, both to one's own men and to the enemy; and as Napoleon I. said, that moral effects are three times the value of material ones, volleys for this reason are to be preferred to any other kind of firing, when practicable.

The opponents of volley firing, as a rule, lose sight of this moral side of the question; they nearly always base their arguments on the relative number of hits made on targets by each kind of firing.

On the offensive, the use of volleys is principally confined to the period of preparation, and therefore belongs to long range fire, as a rule.

Volleys are, undoubtedly, most suited to the defensive, and for use at long halts, which naturally are of a defensive nature.

When volley firing is employed, it should not be executed by more than 120 men (an English company), or at a greater rate than five rounds a minute, in order to obtain the greatest efficacy from it; but the number of successive volleys should not exceed three, without a longer pause to prevent it degenerating into an independent fire, Between each volley there should be sufficient time given for the men to load, aim and fire without hurrying them, and between every three volleys there should be a sufficiently long pause to maintain calmness among the men.

For some further remarks on volley firing, see "Fire Units," on page 171.

2. When men in movement may fire.

The question of allowing men to fire while moving does not mean that they are not supposed to halt to fire, but what it does mean is that these halts are very short, lasting only just long enough to take aim and release the trigger before the movement takes place again.

"Distant firing and frequent halts are not good for preparing the troops for the offensive, because they break their dash, diminish their ardour, and cause them to be too attentive to their losses, which are always deadly at the halting places, whose distances may be exactly known to the defence."

Further, an enemy's fire is only efficacious when the distances are exactly known to him, one of the greatest safeguards of the attack is to move forward so as to constantly alter the range, and hence, after the preparation is completed, the attacking troops should move forward as rapidly as possibly to the short and decisive ranges.

We will first consider the moral side of the question. General Brialmont writes, "When men hear the bullets of the enemy hissing past them, and see their comrades falling around them, they fire in order to conquer their emotions or to try and forget everything, using a full foresight, and often not aiming at all, or even bringing the rifle to the shoulder. 'The instinct of every man,' says Napoleon, 'is not to allow himself to be killed without defending himself.' If the soldier at this moment, is not allowed to fire, he 'would try to save himself by moving forwards or backwards,' while, if he fired accurately, he would soon destroy the enemy. *Fire*, as Col. A. Du Picq has judiciously observed in his *Etude sur le Combat, is the safety valve of the emotions.*" And again, "It is certain that even with trained and disciplined troops, a fire while in motion will have little accuracy after any rapid movements to within a short distance of the enemy; but in these unfavourable circumstances any kind of fire will not have much efficacy. Hence, preference should be given to that kind of fire which least delays the advance, and sustains the *moral* of the men; and this, undoubtedly, is a fire while in movement.

Thus it is judicious to forestall the desires of the men during their advance, and to direct them into a useful channel by allowing them to fire, under the strictest control, a few rounds while moving forward, so as to ensure efficacy of fire at the same time. We have seen that both Germans and Russians suffered severely when they attempted advancing against an enemy without firing, while their losses decreased when they fired, as they approached the enemy's position, by the demoralization their fire caused among the opposing troops.

But as a control over the fire cannot be so well kept up while the men are thus in movement, they should only be allowed to fire in this way, *in a serious manner*, when any real effect is required, when control is no longer possible, *i.e.*, at under 400 yards from the enemy.*

Again, even allowing that while advancing the ranges are constantly decreasing, and therefore the probable efficacy of the fire

* See footnote on p. 152, as to how the fire during movement should be carried out in the advance to this short range.

increasing, such fire during movement cannot be so efficacious as a more stationary fire at even longer ranges. Hence, men should only be allowed, when a serious result is expected, to open a powerful fire while moving at the short ranges, and when a frontal fire can give an efficacious result.

3. When the Bayonet should be fixed.

It has been found that when the bayonet is fixed on to the rifle, it causes the fire to go rather lower than before, and to the side on which the bayonet is fixed. But practically, in the excitement of battle and from the agitation of rapid movement, this result will hardly influence the fire at all, at the shorter ranges over which the assault is made.

The moral effect of fixing bayonets on approaching the enemy is very great, and as the men should fire while advancing to the assault, the bayonets should be fixed at about 300 yards from the enemy's position, just before this assault is begun.

The soldier should have thoroughly impressed on him that the fixing of bayonets in action is a sign to him that the time has come when it is more dangerous for him to retire than to advance, and that if he advances without hesitation the enemy will certainly not wait to cross bayonets with him.

4. The attitude of the men firing.

The attitude of the men firing affects the efficacy of the fire. At short distances, on the practice range, there is not much to choose between any of three positions of standing, kneeling, and lying down, but, as the range increases, the differences in the shooting begin to tell very perceptibly. At the longest ranges, the lying-down position gives the best results, and the standing position the worst.

In field firing, in which the attack is carried out as much like reality as possible, better practice can be made at the shorter ranges in the standing and kneeling positions than when lying down, because the heaving of a breathless man's chest against the ground in this last position affects the steadiness of the rifle more than when it is raised off the ground. This fact also suits the moral and tactical requirements of a fight, because it is dangerous at the shorter ranges to let attacking troops lie down, as it not only tends to destroy the offensive spirit required for an energetic attack, but also it may not be possible to get the men to rise again, especially if they have suffered much. But in order to allow of upright troops to reach an enemy's position, it is essential that the enemy must first be demoralised before the assault is made, so as to reduce the efficacy of his fire, because the upright position suffers most from fire, and the lying down position the least.

Hence, on the defensive, or during the preparation of the attack, when the troops are stationary, the lying down position would always be used. The attack can safely use this position to within about 600 yards of the enemy.

The kneeling position is very fatiguing if used for any length of time, and so it would only be used during a short halt in an attack, when one does not wish to let the troops lie down. This position would be taken up when the lying down position is given up, and it would be used to within about 300 yards of the enemy.

The standing position is the best for the actual assault, during which very short, if any, halts are made.

The lying down position allows of a more frequent use of rests for the rifle, by means of objects on the ground, than any other position. Resting the rifle on such supports is, as a rule, favourable to efficacy of fire, but any decided advantage by so doing can only be obtained from troops who have been trained to it. But in flat countries, or if the ground is covered with long grass, bushes, &c., the lying down position cannot be used sometimes, as it prevents the enemy being seen.

5. The Selection of the Objects to be fired on.

Colonel Bavay, a Belgian officer, who has lately given some interesting notes on the choice of objectives in action, writes, "However important different methods of executing fire may be in influencing the efficacy of the fire, yet this efficacy can only produce a useful effect in a tactical point of view if it stops or paralyses the enemy's movements, and breaks his combinations. Thus we must try more to obtain useful effects than merely the satisfaction of inflicting some losses on the enemy, for however great these latter may be, they are of little use if they do not prevent his final success. It is therefore very important from the first to seek the means of giving to the efficacy of the fire the greatest sum of useful effects, that is to say, its greatest tactical gain; and this should be the principal object assigned to tacticians, as their speculation would be of little avail if they do not give the most capable means of rapidly ensuring victory.

"In order that the losses inflicted on the enemy may produce the greatest useful effect, it is necessary that they should be inflicted on those groups of the adversary's disposition for fighting which, by their *role*, strength, and situation, can exercise a serious influence on the course of the action, and these, as the opportunity occurs, should be immediately destroyed or weakened. It can therefore be said that it is on the best choice of the objectives to be fired at that the greatest tactical result of the efficacy of the fire depends.

"The question of the choice of the objectives is a capital one; it dominates all others in co-union with the direction of fire" unit.

Colonel Bavay's *brochure* of the subject, gives the most complete rules for guidance, and most of the following remarks are extracted from it.

The *rules* for the judicious choice of the objectives to be fired on, are as follows:

I. *Provided the enemy in front is making a serious attack, which it is very necessary to destroy, and that he is within range, we ought to particularly select objects in the part of the enemy's fighting disposition directly in front of us, leaving to the neighbouring troops on the right or left the duty of dealing with the objectives in the lateral parts of the disposition.*

II. *Unless a stronger reason does not require us to act otherwise, we ought to fire on the same objective until we have destroyed it, or at all events, until we have inflicted on it sufficient losses to temporarily paralyse its action.*

III. *It is necessary, in principle, to choose the first objectives to be fired at among the groups of the nearest echelons which threaten the greatest danger.*

IV. *When the attack begins by an artillery duel, and the guns are within rifle range, or when during this prelude to the attack, mounted officers are seen making a reconnaissance of the position or carrying orders, we should select as objectives the enemy's artillery and these mounted officers.*

V. *When the most advanced echelon of the enemy cannot any longer advance, then we must select objectives to fire at, first in the second and then in the third echelon, when they advance.*

VI. *Further, if the firing line is halted for any reason, and offers very bad objectives, then the fire may be directed on objectives in the second echelon, provided such exist with a depth, height, and width, suitable to the range.*

VII. From all that has been said about the superiority of concentrated fire over independent fire, it cannot be too strongly laid down, that *when there are many groups in an objective they should each be fired on successively with a concentrated fire from the greatest number of rifles possible, and every effort should be made to prevent the fire being dissemi-*

nated by its being directed on all the groups at once, in order to produce the greatest tactical result possible during the duration of the fire.

VIII. *As a general rule*, the selection of objectives for infantry can be guided by the same rule as that used for artillery, viz.: *that they should fire on the leading echelon of that arm, which for the moment constitutes the chief danger to the defence, but only if this echelon is within effective range.*

To enable the selection of objectives and the concentration of fire to be effectively and promptly carried out without indecision, the front of an enemy's firing line should be divided into sections, and each one given to a battalion in one's own firing line. Each battalion will select its objectives in the section told off to it, until it has paralysed the action of the enemy in this section, when it may turn its attention to helping the troops on either flank.

The Italian regulations say, "Efficacy of fire and fire discipline are more easily obtained if each section (60 men) has assigned to it a particular zone to fire against, and if a certain interval is left between these sections, while maintaining a strict connection between them."

Hitherto, we have only dealt with frontal fire, but this fire has nothing like the material and moral efficacy of *flank or cross fire*. Hence, troops, unless seriously engaged in front, should always try and make use of this kind of fire, when possible. Those portions of a defending force which are only being opposed by a demonstrative action, may, after putting a definite stop to it, leave a portion to prevent the assailants retaking the offensive, and, with the remainder, if they are even within long rifle range, pour in a fire on the flanks of the assailants, who are making an energetic attack on the neighbouring portions of the position. Even the sound of bullets coming from a flank will intimidate men, and make them hesitate to advance, or even to retire if they are not well disciplined and completely in hand.

Modern battles on an extended scale are only a series of small battles or fights in which bodies of troops, perhaps not greater than a brigade, are engaged. The small fights rage round the different strong points in the position, which act as bastions along the front, and from which a powerful flanking or cross fire can be poured on troops trying to penetrate between them. The assailants, in striving to capture them, try to work round their flanks, and so to surround them on all sides, but in doing so they must expose their flanks to the defending troops in the intervals between the strong points. Thus a skilful defender will find many opportunities of using a flank and cross fire with great effect, and the objective for the fire should be such that, if destroyed, it would have the greatest effect in rolling back or even stopping the advance, due consideration being had to the relative vulnerability and effectives of the objectives formed by the enemy's troop and echelons of attack.

6. Determination of Range and Choice of Sights.

At short distances the correction of the fire is easy, for great errors cannot be made in the choice of the sight; these errors besides will be partly compensated for by the great flatness of the trajectories. With the Martini-Henry rifle in using the elevation for 400 yards,* which is the true elevation for the close fight, and aiming at the feet of the enemy with a fine foresight, the ground is beaten up to 400 yards by direct hits, and the ground beyond is rendered dangerous by ricochets if the ground is favorable. The sight for 500 yards is the best elevation for cavalry at short distances.

At greater distances the correction of the fire necessitates as exact an approximation as possible of the distance of the object, as well as knowledge of the influence of atmospheric circumstances, especially of the wind, on the direction and range of the bullets.

The efficacy of the fire of masses of men, even if unconcentrated, depends, like that of individuals, more on the exact range being known, than on the individual skill or training of the men, for the one is a fixed unalterable quantity, while the other is a variable moral factor, never very reliable in action at the best of times, and which is influenced by whether the men are fatigued or not, by their state of mind from the excitement produced by the effect of the enemy's fire, by the fear of death, and by the surrounding sights and noises. So many things in the field tend to make the firing, even of masses, unsteady, that we feel justified in saying that, *in action the efficacy of the fire of troops (disciplined or not) depends more on the range being known than on the individual skill or training of the men in shooting.* Unless the range is known the very best fire may not hit the mark, while if the range is known the very worst may do so. Thus nearly everything depends in firing, on the range being known, and hence every officer, and even non-commissioned officers, should have a simple pocket range-finder by which ranges can be determined rapidly, even while lying down, up to 1,200 yards, within a less percentage than $\frac{1}{8}$th of the range, so as to be better than judging by the eye. To within $\frac{1}{12}$th of the truth might easily be got, which would only require the use of one sight up to 600 yards, and two

* Or the 300 yards elevation with a full foresight.

sights up to 1,200 yards, according to the calculations already given in p. 112.* The eye is the very worst means of judging distance, for no two men will give anything like the same answer with confidence; practically it is entirely guess work, and the greater the inaccuracy of the method of estimation, the more it is to be deprecated as it causes greater waste of precious ammunition. Therefore the use of a simple, easily and quickly worked pocket range-finder, which can be worked lying down under fire, having as a base the length of a rifle or sword for ranges under 800 yards and a longer one for ranges over this, may be considered absolutely essential, even if it can only read to $\frac{1}{12}$th of the range up to 1,200 yards.

At any distance, *if the range is known only one sight should be used*, and two or three sights will only be employed according to the accuracy with which the range is known. The number of sights to be used is found thus,—Multiply the estimated range by twice the fraction of the range representing the probable error of estimation. This gives the distance over which the bullets must be spread. If the result is 100 or less, then one sight for the estimated range is sufficient. If the result is 150, then use two sights, one for 25 yards under, and the other for 25 yards over the estimated range. If the result is 200, then use two sights, one for 50 yards under, and the other for 50 yards over the estimated range. If the result is 250, use three sights, one for the estimated range, one for 75 yards under, and one for 75 yards over it; and if the result is 300, use three sights, one for the estimated range, one for 100 yards under, and one for 100 yards over it. A little consideration will show how these results are arrived at even mentally.

The ground near the enemy, also affects the number of sights to be used. (See page 115).

Also it must be remembered that men firing down hill are apt to fire higher when excited by the proximity of the enemy than when firing up hill, and so a lower sight should be used in the former case than in the latter for the same range.

7. The Distance at which Fire should be opened and the Number of Cartridges to be used to Attain a Definite Object.

No definite rules can be laid down for such an estimation, but it is greatly governed by the existing phase of the fight, the available

* This is all the more necessary in the English service as the sub-division of the English company does not lend itself easily to the use of three sights over 800 yards.

supply of ammunition, and the facility of replacing it, all of which must be well considered in order to come to a conclusion whether such a consumption is justified. This is much more important for the attack than the defence, as the means of supplying men constantly moving towards an enemy over fire-swept ground are far harder than those of supplying stationary men under cover.

"Commanders of companies in the fighting line ought, on principle, to order commence firing, not when the infantry fire of the enemy becomes dangerous, but when the line has got to such a distance from the enemy that its fire is effective.* In advancing to the attack, and as soon as the artillery preparation is at an end, they should endeavour to push their firing line within effective range of the enemy, that is in principle (theoretically) up to 400 yards, then immediately to reinforce the line in each company, and then to commence firing.

"Nevertheless, the most determined advocates of this close fire allow that the troops of the first line can only fulfil the requirement of getting within effective range of the enemy when the ground on which they move is particularly favourable. Should it not be so, fire must be opened before arriving at 400 yards, that is to say at some distance between 800 and 400 yards.

"In the German army, it is held that when on the defensive, fire should be opened sooner than on the offensive, as a rule at 800 yards. This divergence of practice is justified by the facts that, for the defensive, the ranges are more accurately known and may even be marked, the supply of ammunition is easier, the riflemen are under cover and can fire from a rest.

"It is needless to say that if, before arriving at 800 yards distance, the enemy should offer a favourable mark, a fire of masses would be directed upon them.

"All the commanders engaged, but particularly those commanding units not yet within effective range of the enemy,† should always try to estimate the amount of ammunition which must be expended to attain a definite object, and consider whether the immediate situation of the fight, the local available supply of ammunition,

* The effective range at any moment depends on the accuracy with which this range is known, and the size and exposed height of the objective. The general opinion, however, is that men should be allowed to fire a little early in the fight, while advancing, to keep the offensive spirit up and not to demand too much from them.

† For example, troops in the first line while the artillery preparation is going on, or troops in second line, or troops sent to execute a false attack or a delaying action.

and the facility for replenishing it, will justify the required expenditure.

"In the case of a false attack or a delaying action, it may be absolutely necessary to execute a vigorous fusilade, or to keep up a more or less lively fire at distances more or less considerable, although there may be little hope of inflicting serious loss. The object to be gained, in these cases, is to deceive the enemy and to keep him tied to the spot; the fire should therefore be regulated accordingly, but the commander should always take account of the amount of ammunition required for the action which he is ordered to carry out, and arrange for a proper supply of cartridges to replace the expenditure.

"These considerations of supply, therefore, exercise great influence in fixing the moment when the order to commence firing should be given. It is quite certain that a body of troops supplied with an unlimited amount of ammunition would scarcely need to think of waste, and might open fire at much greater distances than those which have been laid down for ordinary practice. Moreover, it is not to be forgotten that, in an attack, opening fire at too great distances diminishes the offensive power of troops, and gives a protracted character to the attack. It may be added that the moral force of the troops is injured by seeing that their fire is ineffective, whilst that of their adversary increases in power.

"Commanders of companies judge the expenditure of ammunition and estimate the number of rifles to be brought into play by certain very simple data," obtained by calculation from the results gained at peace experiments on the effect of modern rifle fire at various ranges on different formations, and on the different positions of standing, kneeling and lying down.

Of accurate independent fire, certainty of effect is only to be obtained by the concentrated fire of a great number of rifles on the same object. In this case only can we count on a certain percentage of hits, which will depend on the height, breadth and depth of the object.

The following simple data are given by Major Von Metzier:—

"One hundred shots give at 400 yards twenty hits, at 800 yards ten hits, and at 1,200 yards five hits, when the object represents a line of men standing up and is divided into spaces equal to the breadth of a man.

"Against a kneeling enemy, at medium and long ranges, the results would be less by a half, and if he were lying down they would be one-fourth only. Against an extended line the results would be a half, third, &c., according to the density of the line; against a company column the losses up to 800 yards would be more considerable, and beyond that distance would even be doubled."

All the numbers given in the above statements can only be approximative as they depend on the degree of concentration.

To get a good effect against objects over 800 yards distant requires a large expenditure of ammunition, and if it is to be quickly attained, as should be invariably done when possible, a proportionately large number of men must be employed. Under certain circumstances, however, a good effect against large objects, such as batteries and closed bodies of troops, may be obtained up to 1,400 yards.

As an inefficacious fire weakens the moral force of the men delivering it, and raises that of the enemy, therefore before opening fire the company commander ought always to consider if the consumption of cartridges thought necessary to attain a certain object is in harmony with the result hoped for, and is justified by the situation of the fight and the supply of ammunition available. If the company commander sees no result from his fire he should at once stop it and wait for a more favourable opportunity for re-opening fire.

With the question of the amount of ammunition required for a definite object, the distance of the object is intimately connected. We see from the above tables that *the longer the range, the greater is the amount of ammunition required to be expended to gain the same result.* Thus, this fact, combined with the supply of ammunition available, and the *rôle* that the particular body of troops has to play, will decide whether the fire may be opened at once or reserved for a closer range. The closer the enemy is approached the harder it will be to break off the fight, should this be required to be done.

Having considered the range and the amount of ammunition that will have to be expended in attaining the object in view, the company commander will have further to consider whether the existing phase of the fight, or the ammunition that he has, will justify the expenditure.

If the combat is in real earnest, such as a decisive battle, every round must be retained by the attack for the shorter and decisive ranges. Hardly anything will justify a single round being expended at any range beyond the nearest that can be got to, though, from the moral encouragement that returning fire gives the men advancing under fire, a few rounds, under the most severe control, may be fired during the advance to the decisive ranges.

Then, again, in such a fight, it is impossible to supply ammunition when the real attack has once begun.

In temporising actions, or false attacks, fire may be opened at longer ranges, as the attack will not be pushed home; this enables it to be broken off at any moment, and the supply of ammunition is facilitated.

If there is no artillery, or if there is an inferiority in this arm, infantry will have to prepare its own attack, in which case a much larger amount of ammunition will have to be expended, and a proportionately larger supply will have to be provided for. 120 rounds, fired only at the rate of one a minute, will be expended in two hours.

The amount of ammunition to be expended cannot be formulated by any rules, and experience alone can form a guide to this consideration, and this experience is entirely wanting in the English service.

After all, we see that there are no exact rules that can be given with regard to estimating the exact amount of ammunition to be expended to attain a definite object. All that can be said is, that if a decisive result is required, the ammunition must be saved for the shortest range possible. The shorter the range, the men being in hand, the more effective the fire. The more important the objective fired at is, in a tactical sense, the greater is the number of cartridges that should be poured on to it.

If we do not wish to close with the enemy, then get to the nearest distance which will still allow us to retire unimpeded, so as to obtain the greatest efficacy to injure him as much as possible. To break an enemy's strength in every way, however small, is the object of war. The sum of several small effective efforts will, in the end, amount to a large result.

8. Determination of the Force Required.

Having decided on the amount of ammunition to be expended, the next thing is the determination of the force required in the firing line, in order that the number of cartridges deemed necessary may be expended in the desired time.

It may be laid down that when an earnest attack is contemplated, it should be carried out in the shortest time possible, and with the greatest determination. *Clearness of design and energy in execution is, then, essential for success.* A long, drawn out, hesitating attack is fatal to the offensive spirit and to victory. *The first condition of all is to gain a superiority of fire. Victory is the reward of doing so.*

As fire is the preponderating element in combats, the supports should be moved up to the weak extended skirmishing lines as soon as fire is to be seriously opened; it is essential that a powerful combination of fire should be opened on the enemy from the very first, as soon as an effective range is reached.

Rapidity of action is best obtained by the suddenness of fire, which is one of the principal conditions of its efficacy. The moral influence of a material result gained is the greater as this result is obtained in a shorter time.

As the moral effect of sudden and rapid losses is so great, *it is best to expend the required ammunition as quickly as possible, by employing the greatest number of rifles that can be conveniently used at one time on the same objective.*

"The useful effect of a fire depends on its accuracy and rapidity, but this result is better sought in the medium and long ranges by means of the accuracy of the fire and the number of men made to fire, rather than by too great a rapidity of fire."

It should be remembered by the leaders that *the moral effect of fire upon troops is the greater the more it is concentrated, not only as to place but also as to time.* A whole company firing five rounds per man will produce a greater impression than the third of a company firing fifteen rounds per man.

"On the offensive, moral and material superiority consist, at the present day, in not being afraid to expend the necessary number of men, and in getting so near to the enemy as to be able to make the effect of our fire felt very quickly, and thus to inflict rapidly on the enemy the amount of loss required to be decisive of success." (*Moderne Feuertaktik*). Nevertheless, it is evident from many Continental writings, that voices are now being raised in favour of the maxim that "the assailant ought to open fire as soon as the fire of the defensive party begins to be effective." The same author adds "In perfectly level country one can rarely approach within 800 yards of the enemy without covering the advance by fire. The losses would become, in fact, so heavy that the fighting line would be insufficient to ensure a superiority of fire. Even if it were possible to arrive within 400 yards of the enemy's position, as has often been recommended, it cannot be denied that the men being without cover would, at this range, be in a very critical position."

Thus the rule is to gain a decisive effect in the shortest time, and to do this, we must bring up the greatest number of men possible, in order not to reduce the useful effect of the fire by a too great rapidity of fire, which injures the accuracy. The number of cartridges to be fired are better expended by a large number of men firing a few rounds in a short time than by fewer men firing more rounds in a longer period. In the former case also the men's personal supply of ammunition will not be so weakened for further action,—a very important point.

One, two, three, or four rounds a minute is quite quick enough for firing under ordinary circumstances, though this may rise to ten rounds a minute just before the time of the final bayonet charge. Sufficient accuracy at ranges over the short distances cannot be expected with a greater rapidity than four rounds a minute.

If a decisive effect is not aimed at, then only enough rifles may be brought into the firing line to check the enemy seriously should he try to advance.

The German regulations say that if two sights are employed, there is no advantage in firing with less than eighty men (a third of a company), and if three sights, a whole company (250 men) should be employed.

The Austrian regulations say that "To ensure a reasonable effect with long range fire for a given expenditure of cartridges, it should not, as a rule, be undertaken with bodies of less than fifty men, and then only against deep columns and masses, such as company columns, closed supports and reserves, or thick shooting lines in the open up to distances of 1,000 yards, or against battalion or squadron columns under like conditions up to 1,200 yards. If any of these objects are partially hidden, they should have a greater depth than indicated above to justify their being fired at. Batteries of artillery and large general staffs may be fired upon up to 1,200 yards under any circumstances."

If it is proposed to employ infantry against artillery, the Germans say, a distinction must be made if the artillery are occupied elsewhere or not. When a battery is in action against artillery, a single company (of 250 men) may be opposed to it at from 900 to 1,300 yards. But if it is not occupied elsewhere, and can turn its fire on the opposing infantry, then the Germans would employ four companies against a battery, because the result of experiments made by both the French and Germans has shown them that at the above ranges a battery produces an effect equivalent to twice and four times, respectively, that of a company of 250 men*. Similarly,

* An English battery will probably require more infantry to silence it, from its superior shrapnel projectiles. Each shell of the new 13-pounder field gun carries 116 bullets. A battery of 9-pounders can even now defend their own front, if the ground is open for at least 1,000 yards to this front.

when infantry seek to prevent artillery from taking up a position, it should employ at least a battalion, so as to spread death amongst the teams and men, and throw it into disorder before it can unlimber.

Fire Units or Groups.

Fire units are necessary for two reasons.

1. To obtain the maximnm efficacy of fire a large number of men must be brought into the firing line, and their fire must be concentrated. But a dismounted officer's control cannot be felt over a very wide front in action, and hence the firing line must be divided into fractions which form the *fire units.*

2. In obtaining the number of rifles required in the firing line they must not be pushed in without order or organization, else control will vanish. For this purpose, regular organized units only must be put into the line at a time, and the number of rifles must be counted at so many *fire units* or *groups*, and not as so many men simply.

These units may be of various sizes, and should invariably be sub-multiples or fractions of the regular tactical unit—the company. Another point is, that these sub-units must not act independently, or else we run a risk of losing power of control, and of the great effect of concentrated fire.

To get the greatest number of rifles into play, the men must be placed in line in single or double rank ; long lines, however, cannot be commanded by voice, and, moreover, the ground rarely lends itself to their movements. It is very important to remember that the power of directing the fire depends more on the front occupied by a unit than on the strength of this unit in men. The longest effective line that can be commanded by voice or whistle, by a dismounted man, even at a distance from the enemy, is a front of about fifty paces. This is about the maximum front over which a dismounted man's control can be felt in action, which gives fifty rifles in one line, or 100 rifles in two lines. An exact front of 50 paces would not, of course, be taken as the fire unit, but the nearest organized tactical unit whose front most nearly coincided with this distance would be so taken.

If we employ fewer than fifty men at long ranges to form a fire unit, we run the risk of losing the great effects which a concentrated fire is destined to bring about, and besides, the control of the firing would fall into more hands than neccessary for such a fire.

The smallest permissible groups of men should be such as to prevent the control of the firing from falling into the hands of inexperienced leaders. The fewer the groups or units, the easier is the direction of the fire controlled, but the harder they are to command individually.

It is very essential that the important duties of the command of each unit (*i.e.*, the direction, kind of firing, judging the distances, etc.) should, as long as possible, be carried out by officers, and not by the non-commissioned officers, who should see that the men conform to the officers' orders, and should transmit these orders along the line. These are most important duties, and must not be neglected for more ambitious ones.

Taking an English company at war strength, or about 100 men, these, if extended at one man per pace, as would be the case in a decisive fight, cover 100 paces, which would give two fire units of fifty men, or half a company each, under an officer.

As the enemy is approached, the difficulties of control and command increase, but by this time the objects to be fired at have been more clearly indicated and impressed on the men, and hence the fire units may now be reduced in size to twenty-five men, or one quarter of a company each, each under a sergeant. This shows the necessity of having non-commissioned officers trained to lead in action.

Further, it is highly necessary that the men should be trained to work in groups when at a distance from the enemy, and that their independence of action is only to begin when control is no longer possible; that they must do so because it is best for the mutual good of the whole, and to obtain the best effect of their fire by concentration; this can only be done by fully impressing on the men by practical experiments the inaccuracy of independent fire at ranges beyond 400 yards, when these have to be guessed, and that this can only be corrected by their voluntarily placing themselves under the nearest leader to obtain the required efficacy by concentration of fire. This is particularly necessary when fresh supporting troops arrive irregularly in line; they should be taught to place themselves under the commanders already in the front line, and not to look for orders from their own officers only unless they have been moved as a complete body into a gap.

As we still get nearer the enemy, the larger organized units are broken up from the difficulty of controlling fire, but the shorter the range the less important is concentration, and thus smaller groups are permissible; but *groups of from 8 to 16 men each may be considered the minimum and maximum numbers respectively for effective fire.* Under a close fire a single man cannot look after more than 16 men at the most in extended order, so as to see that they are carrying out exactly the orders of the battalion officers. Smaller groups than eight men would split up the commands too much.

Some experiments that have been made officially in France since 1878 have shown, "That individual firing, as far as accuracy is concerned, is superior to volley firing; that volleys by groups (about 15 men) are superior to volleys by sections (60 men); and volleys by sections to those by half-companies (120 men). But it must be remarked that the differences are so slight as to give none of these kinds of fire a marked superiority over the others." This official statement has, however, been disputed by individual writers. The anonymous French author of *Le tir de l'infanterie aux grandes distances*, who has been much quoted, writes: "The best volleys are those fired by groups, but the maximum effective of the body firing ought not to exceed 100 men in two ranks. The more the fire unit is reduced in size the better is it in the hands of its leader, who can better look after it, while the men can hear him and execute his orders better. The regulations wisely order the commander to give the word '*Fire*' in volley firing, when he sees the rifles steady: that is when the men are ready and have finished aiming. But the simultaneous readiness of the whole unit will be the harder to obtain, according to the greater number of men it contains; if the command '*Fire*' is given before they have all aimed, there will be many shots fired wide of the mark; if he waits longer, he will fatigue those ready. . . Group volleys can be executed with the men in two ranks or deployed. The same can be done with volleys from demi-sections (25 men); but if these are deployed, the front will be more than 30 yards. It is not possible to execute good volleys with a larger body of extended men."

Thus, small groups are the best to use, in order to gain the greatest result from the fire. But the precaution given on p. 91, with regard to pauses, must be all the more carefully adhered to as the fire units become smaller.

Even if the French official conclusion is correct, that volley firing is rather less accurate than a controlled and steady individual firing, yet at all ranges beyond the short ones volleys are preferable, from the moral results and power of control they give, while the difference in accuracy is most likey to vanish in the battlefield, from the ranges not being known, and from the excited state of the men.

When firing with two sights, alternate units of whatever size they may be, or half of each unit may each fire with a particular sight. When firing with three sights (*i.e.*, at ranges over 800 yards when the distance is estimated by eye), it will be best to tell off a third of each unit to fire with the same sight. This can be done easily, as the enemy is still more than 800 yards off. Whole groups, and not alternate men, should use different sights, so that their commanders may more easily see that their orders are being obeyed.

Hence it is most essential that each fire unit should have a leader to control and direct its fire.

The position of each fire group or unit must be looked upon as that of a gun in a battery, or as a battery in a long line of artillery. The orders for the direction of the fire is passed down the line to the leaders, or told them before the action is fully committed, *i.e.*, what they are to fire at, the number of rounds, the rate of fire, the kind of fire, the sight each is to use, &c., and any other such orders, and then the leaders order their groups or unit to fire as commanded, and see it carried out. The fundamental rule of artillery action of massing the batteries and concentrating the fire in the earlier stages of the fight, applies equally well to infantry—mass the fire units or groups and concentrate the fire on the important points of attack.

Immediately after the war of 1870-71 it was generally thought that the greatest independence should be given to the individual soldier in his actions, but this idea soon died out abroad, while it has ever since been retained in England. *Mutual and not independent action is the secret of success in war*, and for mutual action to exist, there must be discipline, direction and control. The word "independent" should be cut out of every regulation and drill-book. Every action can be classified under "individual" (which does not necessarily imply independence), and "mutual" action. The independent training of men is an evil that cannot be too strongly repressed; present conditions require the men to be trained to work mutually in groups under a leader, and not independently. The advantages which a firing-line, divided into groups or commands, has over a continuous firing line, with each man working according to his own lights, are:—

1. It enables a better control over the men to be maintained, so that they are kept better and longer in hand.

2. It enables a concentrated fire to be kept up even at the shorter ranges, and on the objects required to be fired at.

3. The pauses, so necessary to enable control to be kept up, are facilitated.

4. It conduces to a more rigorous execution of given orders.

5. It helps to avoid waste of ammunition—the group leader having the power of moderating the fire according to circumstances.

6. It permits of a more rational utilization of the cover given by the ground, and of a more energetic advance in the attack.

7. It gives to each man a contact with his comrades in the group, which increases his feeling of security and confidence by the moral protection it affords.

8. It presents to cavalry a series of organised groups quickly formed and capable of sufficieut resistance.

9. It allows of volleys to be executed at much shorter ranges.

The independent firing of the French in 1870, and of the Turks in 1877 should be taken to heart by all as a warning of how not to act. The men knew their rifles could carry long distances, and with little regard to aiming or to range, they fired away in the direction of the enemy without guidance or control. Although heavy losses were thus inflicted when directed on large closed bodies, yet such firing never beat off a determined attack in open order, and it is liable, moreover, at the most critical moment, to cause troops using it to run short of ammunition, as so frequently happened to the French, necessitating of course their retirement. The Germans, on the other hand, when on the defensive, never opened fire beyond a range of about 400 yards, and yet their fire, steadily and well delivered, the result of stern discipline and training, was invariably successful.

By "groups" it must not be thought that a closed body of men is intended—the group may be extended. The word "unit" perhaps more fully expresses its meaning.

The leaders of these groups, in the final stages of the fight, are the officers and non-commissioned officers, but the latter have, when the enemy is still distant and the combined groups are large, their special invaluable duties in the "control" of the fire, and so they must never presume to take seperate command of a group unless they receive the order from an officer, who finds the control getting too difficult, to do so, or if the officer is killed or wounded.

The men in peace time must have a full and clear conviction impressed on them of the value of mutual action, and of the uselessness of independent action, for it is only by so doing that they will have the discipline to voluntarily place themselves when in action under the control of the nearest leader, whoever he may be.

C. B. M.

PAPER VI.

THE LYDD EXPERIMENTS OF 1885.

By Capt. G. S. Clarke, R.E.

The right reading of the results afforded by experiments is evidently of the first importance. Danger always exists, that a too hasty generalization from data obtained under conditions whose influence is insufficiently taken into account, may create an erroneous impression, and lead to mistakes, subsequently translated into action. It is certain that in some cases diametrically opposite and mutually destructive views are based upon the same experiment. Take the Inchkeith trials of 1884 as an instance in point. Here, under peace practice conditions, with smooth sea, and not even a rifle replying, the ship expended 15,210 machine gun bullets, with the result of killing 15 dummies. The said dummies remained, of course, in fixed positions throughout the trial, and one unfortunate, whose duty it was to look after the muzzle derrick—a duty he might have performed with a boat-hook from the loading way—had to stand on the platform, fully exposed throughout the firing. He was killed three times, though with very average luck he would have escaped altogether, thus reducing the butcher's bill to 12, or one dummy to 1,267½ rounds. Now consider the shrapnel practice. In 15 rounds of 10-inch shrapnel fired as mere target practice, *one ball* found its way into the emplacement, hitting nobody. This was so eminently unsatisfactory a result, that a second series of 15 rounds was determined upon. The experience gained was carefully applied; yet, in the first 10 rounds, no dummy was touched. In the last five rounds, however, two effective bursts were obtained, with the result that three dummies were killed, and one wounded. Thus, in twenty-five rounds, fired under ideal practice conditions, not a single dummy was hit, and the whole result was probably due to two rounds out of the 30.

So far the facts of the Inchkeith experiments; how is their meaning to be read? Supposing the ship had been engaging two guns instead of one; and suppose she had been herself under fire, remembering that any sort of gun would be able to account for the machine guns' crews who had no protection; how much may we discount the total of hits obtained by the machine guns? Again, suppose the dummies had been able to move into safer positions when not actually performing their duties, and that when the fire was hottest they could have taken cover for a few minutes; what further reduction of effect may we assume? As for the shrapnel practice, we have two effective rounds in thirty deliberately fired at a passive target. We knew before-hand that a 10-inch shrapnel containing 210 balls must, if it burst in the right place, prove tolerably destructive to a little knot of men grouped in a few square yards; but what are we to think of the chances of obtaining the right kind of burst under service conditions? The above will serve as an illustration of the difficulty of making positive deductions from experiments of this class. What wonder that opinion ranged between limits about as wide as the following:—

(*a*). 'The effect of the machine gun-fire of a ship will be much less than is expected, even in the case of an emplacement so well designed to increase it as the Inchkeith pit. Given a BL gun loading at elevation, a little steel plate well disposed, and an emplacement of a different type, all the machine guns of a ship will not keep such a shore gun silent. Even in the case of the Inchkeith gun, the very worst that the ship could do would be to temporarily keep it silent, at a vast expenditure of ammunition. If there were one or two machine guns ashore to reply, the ship could not possibly hope to effect as much as this.'

'As for the shrapnel fire of a ship, the chances of an effective hit are so small that this mode of attack is not worth trying, which perhaps explains the fact that French ships do not carry shrapnel. Since almost anything will keep out a shrapnel ball, and the chances of scoring a hit with the base are remote, this class of fire is the less to be dreaded.'

(*b*) 'The effect of modern machine gun-fire is so terrible, that no barbette shore gun could possibly be served within machine gun ranges. All guns, except on very high sites must, therefore, be of the disappearing class.'

'Shrapnel is a most effective mode of attacking barbette guns at ranges up to 3,500 yards at least. The present very small allowance of shrapnel carried by H.M. ships should therefore be much increased.'

Between these extremes there is room for a long series of opinions finely graduated, so that it is not too much to say that on no two minds was an identical impression produced.

In the following analysis of the results of the Lydd experiments of 1885, therefore, any deductions set forth have no claim to more value than attaches to an individual view.

The following were the subjects brought to trial :—

(1). Breaching of earth parapets—9·2-inch and 6-inch BL guns; 8-inch RML 70-cwt. howitzer.

(2). Breaching of cellular parapet formed of wire gabions—8-inch BL gun.

(3). Effect on parallels and approaches—6-inch BL, 5-inch BL, and 12-pr. BL guns; 6-pr. Hotchkiss quick-firing gun.

(4). Effect on field magazines and powder recesses—8-inch RML gun, 70-cwt. howitzer.

(5). Protection afforded by disappearing system against curved cannon fire—8-inch 70-cwt. howitzer.

(6). Protection afforded by steel plates against howitzer shrapnel—8-inch RML 70-cwt. howitzer; 6·6-inch RML 36-cwt. howitzer.

(7). Effect of enfilade fire against flank of a provisional work—6·6-inch RML gun; 8-inch RML 70-cwt howitzer.

(8). Effect of common shell and shrapnel against sap-heads—12-pr. BL gun; 6-pr. Hotchkiss quick-firing gun.

(9). Effect of quick-firing guns against obstacles—6-pr. quick-firing gun.

(10). Use of wire netting to protect parapets from blast—8-inch BL gun.

(11). Effect of high explosives as bursters of shells—wet gun-cotton; blasting gelatine; metadinctro benzol.

(12). Trial of wall-piece—0·6 inch BL.

I. Breaching.

One of the principal objects of the experiments was to obtain results in sand for direct comparison with those in clay. No pure sand being available, a mixture of two parts of sandy soil to one of clay was made. The weather being dry, the compound well represented a light loam, which, however, apparently stood at 45° slope.

(*a*). *9·2-inch B.L. gun*, 30-foot clay parapet with 45° exterior slope. Range 1200 yards. Common shell.

Six rounds were fired giving two hits, which effected a breach. The first round dug about 13′ 0″ into the parapet; the second trenched through it, cutting down the crest 3′ 6″. The total earth movement effected by the two shells was 61·9 cube yards.

Loam parapet. Exterior slope 15°.

In three hits the exterior crest was cut back 8′ 0″; the crater maintained a slope of about 15°; and the total earth movement was 14 cube yards.

Deductions. It is perhaps unfortunate that similar exterior slopes were not employed, in order that the comparison of the two parapets might have been perfect. The value of flat slopes in the case of clay is, however, less pronounced, and the first shell on a 15° clay slope would probably have left a steep-sided crater, which would have served to hold the next projectile. As the experiment stands, the enormous superiority of the light loam was strongly attested. The earth movement effected by a single shell was 30·9 cube yards in clay, against 4·7 yards in loam. In other words, it would require about six and a half times as many 9·2-inch common shell to produce in sand the same breach that was made in clay. Even thus, the full advantage is hardly stated.

(*b*). *6-inch B.L. gun.* 30-foot loam parapet. Exterior slope 15°. Range 1,200 yards. Steel common shell.

In all, 15 rounds were fired, yielding eight effective hits. The total earth movement was 10 cube yards. The exterior crest was cut back 6′ 0″ only, the front slope of the crater remaining at about 15°. Of the 15 rounds fired, five were defective in line, and these, by filling in the breach, distinctly retarded its progress.

Deductions. These results compare directly with those obtained under similar conditions against a clay parapet in 1884; except that steel shells were used last year, which makes the comparison *less* fair to the loam. In the clay parapet, a breach with an average depth of 4′ 0″ was effected in 8 effective hits, with a displacement of 31 cube yards. The crater produced by the same number of hits in sand was less than one-third in content; but covered a greater breadth. As a moderate estimate, it would have required 40 effective hits to make a complete breach in the loam; or, on the scale of the 1885 practice, 75 rounds. Thus the comparison of rounds is 7·5 to 1. The effect of an error of direction in spoiling the prospects of the breach in sand is significant. Under siege conditions, projectiles will not all be correct in line.

(*c*). *8-inch 70-cwt. howitzer.* Loam parapet as above, but exterior slope 45°. Range, 1,200 yards. Common shell.

Of 30 rounds fired, 20 effective hits were obtained, breaching the parapet to an average depth of about four feet, and breadth 13 feet; earth displacement 36 cube yards. Two rounds, owing to error in line, retarded the operation.

Deductions. A similar parapet, built in clay, can be breached in nine effective hits, at a maximum estimate. The comparison is, therefore, 20 : 9 in favour of sandy loam. As might have been expected, the light soil showed much greater relative superiority under the fire of the high velocity gun than under that of the howitzer, and in 1885 the howitzer easily beat the gun.

(*d*). *8-inch 70-cwt. howitzer.* Loam parapet. Exterior slope 15°.

Out of 15 rounds fired (two premature), seven effective hits were obtained, and two blind shell. The total result was an earth displacement of only 11 cube yards.

Deductions. There was no attempt to make a complete breach, which is perhaps to be regretted, as a direct comparison between slopes of 47° and 15° *in loam* might then have been instituted. It may be taken, however, that not less than three times as many effective hits, or 21 in all, would have been required.

The comparative figures are :—

No. of effective rounds required to breach.

		Clay.	Loam.
15° slope	6-inch BL gun.	8	40
	8-inch howitzer.	13	21
45° ,,	8-inch howitzer.	9	20

II. Cellular Parapet.

8-inch BL gun. A parapet constructed of two tiers of square wire net gabions, filled up with sandy loam. Exterior slope 45°. Range 1,200 yards. Common shell.

The object of the experiment was to ascertain whether, by the cellular construction, any increased power of resistance to single hits might be obtained. In the case of coast defence guns, it is specially desirable that they should not be laid bare by a single lucky shell. Even machine gun protection, or a mere visual blind, is of importance.

In all nine rounds were fired, of which seven formed a complete breach; average depth about 4′ 3″, breadth 12′ 6″.

Deductions. The shooting of the gun was excellent, all the seven effective hits being exactly in line, which accounts for the rapidity with which the breach was formed. Unfortunately there is no comparative experiment with an ordinary parapet. There appears, however, to be no reason to believe that the cellular construction confers any advantage, even as regards single hits.

III. Parallels and Approaches.

(*a*). *6-inch BL gun.* Parallel in sandy loam; rough section, about 17′ 0″ at ground level. Range 800 yards. Cast iron common shell.

In 13 rounds fired, the parallel was hit seven times. Single shells striking near the foot of the exterior slope trenched easily through it: 5·6 cube yards were displaced by a single hit.

Deductions. This result differs little from that obtained in clay. In a weak section of this form there is not *mass* enough, either to turn up the shells or cushion the burst and direct it upwards.

(*b*) *5-inch BL gun.* 16 rounds were fired, yielding six hits. Single shells striking 2′ 0″ above the ground level trenched through the parallel. Two shells striking on the same spot six inches above the ground level, did not nearly make a breach, and displaced altogether 1·7 cube yards. The maximum displacement by a single shell was 2 cube yards.

Deductions. The shooting was rather better than that of 1884, when only four hits were obtained in 13 rounds. The sand parallel showed a superiority which cannot, however, be well expressed in figures. Everything appears to depend on where the hits occur.

(*c*). *12-pr. BL gun.* 10 rounds were fired, giving seven hits, of which six occurred in the same crater, and can be regarded as cumulative in effect. The parallel was not breached, the crest being only cut down 1′ 0″, and the trench in rear still affording 7′·6″ of cover.

Deductions. In clay, it was considered that four well-placed rounds would have effected a breach. In the present case, it seems certain that at least 10 such rounds would be required. Meanwhile, no complete breach has yet been made in a parallel by the 12-pr., and it is sufficiently clear that such an employment of this gun would be a useless waste of ammunition.

IV. Field Magazines and Powder Recesses.

8-inch, 70-cwt. howitzer. Range 2,400 yards. Common shell, service pattern and special pointed.

(*a*). *Field Magazine.* The covering mass was of sandy loam 7′ 0″ in thickness above the magazine roof; exterior slope 45°. A double layer of rails, 24′ 0″ long, inclined at an angle of 10°, was built into the covering mass, the lower ends of the rails being buried in the natural ground, so that it was impossible for a shell to get under them. The lower layer was formed of 56-lb. steel rails, the upper layer of 36-lb. iron rails. The shortest line entry into the magazine at the angle of descent of 34° 20′, passed through 12′ 6″ of sand and the double layer of rails.

In 45 rounds fired, 10 hits were obtained, of which only one produced any effect on the magazine. This round struck the top of the covering mass, and burst well, making a crater 15′ 0″ in diameter, 4′ 6″ deep in the centre, extending to within six inches of the layer of rails. The latter were slightly bent, and some of the magazine frames were started. This was the total damage, and the effects of the remaining hits were insignificant-- shallow craters, or scoops, filled up and obliterated by the one good round.

Deductions. This experiment unfortunately cannot be compared directly with that of 1884; since the design of the 1885 magazine was decidedly superior. In the previous year two magazines were tried, one with a roof of 10″ × 10″ for baulks, carrying a double layer of 36-lb. rails and 7′ 0″ of clay; the other having a roof of 12″ × 12″ oak baulks, and a double layer of 36-lb. rails; then 1′ 9″ of clay, with an upper horizontal layer of 10″ × 10″ fir baulks, and a double layer of rails; finally, about 3′ 0″ of clay. The attack turned the defences in both cases. The first magazine was blown in from the front, the shell thus avoiding the whole of the iron and timber protection altogether. In the case of the second magazine, the upper protecting layer was easily broken through; while one round cleared the upper protecting layer, and blew in the sheeting. The 1885 magazine was not exposed to this danger, as it could only be attacked through the rail layer.

Some points are, however, worth notice. The shells were well held by the clay. Two of them striking the flat top entered with little loss of angle of descent. The best crater was fully 6′ 0″ deep, and 15′ 0″ in diameter. The masses of clay were flung to some distance, so that the action of the shells on the covering mass was distinctly cumulative. In the sandy loam, the tendency of the shells to turn up was marked, notwithstanding the high angle of descent—34° 20′. One blind shell struck the exterior crest, and just came out of the sand 5′ 0″ further on. Another shell scooped blind, while two scooped and burst in the air with delay. Thus the effect of the sandy loam was to neutralize almost entirely the value of the delay action fuze, shown to be very effective in clay. In 1884, a penetration of 28′ 0″ was recorded; in the sandy loam, no blind shell was held, and the maximum penetration of a burst shell was about 3′ 6″.

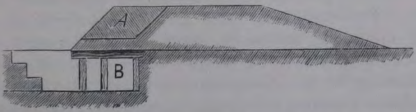
It is to be noticed that this experiment necessarily failed absolutely as a practical test of the security of a field magazine. If it were customary or essential to build up an excellent square target within 2,400 yards of the guns of a fortress, and cause the defenders to be informed that this target was a magazine, the data obtained would have been more significant. The security of a field magazine does not depend on the amount of overhead protection nearly so much as on the fact that the enemy can rarely or ever know exactly where it is. If, by means of balloons, the defence is able to localize the position of magazines, and direct the fire aimed at them, the case is altogether different. Meanwhile, concealment is a more real protection than successive layers of steel rails. The experiments of 1884 and 1885 serve to show the maximum effect of the shells of the 8-inch howitzer against structures of a particular class. The practice last year was inferior to that of 1884—the *total* hits being:—

Year.	Target. Square feet.	Hits.			Total rounds.
		Effective.	Non-effective.	Total.	
1884	2194	4	8	12	27
1885	1863¾	2	8	10	45

It is perhaps worth noting that the deck of a ship 300 feet long with 30 feet beam, anchored end on to the howitzer, would have been hit 43 times out of 45 rounds!

(*b*). *Powder recesses.* Range, &c., as above. Three recesses of the design proposed by Colonel Baylay, R.A., formed the target. (*See Plate VIII., Effect of Projectiles on Masonry and Earthwork, Vol. X.*) The centre recess contained 12 cases, and was, like the magazine, protected by railway bars; those on the flanks six cases each; the intervening traverses were 25′ 0″ thick at the base. Out of 30 rounds fired, seven hits were obtained, of which three could not have been effective under any circumstances. Of the remaining four, two formed large craters 4′ 9″ and 4′ 0″ deep, and about 15′ 0″ in diameter; but, as the line of the shells fell on the traverses on either side, the recess in the centre was undamaged.

Deductions. The experiment proves nothing directly. As the shells fell, they could not well have fired the powder in the recesses, and it is unfortunate that a more dangerous hit was not obtained. It is claimed that the recesses, which showed only a straight length of parapet in front, offered a more difficult target than the magazine; but this is hardly fair to the latter, which might have been so constructed, as to prevent an identical appearance. If a magazine really requires protection against the cumulative effect of 8-inch howitzer shells, it becomes, in many cases, impossible, and the alternative recesses, which entail much less labour, appear to offer the best solution of the storage difficulty. Distribution of powder is evidently advantageous, and a subsequent experiment, in which a shell was buried 3′ 0″ in front of the sheeting of the centre recess, and exploded electrically, showed that 25′ 0″ traverses provide sufficient protection to the cases stored on either side. This thickness might probably be reduced with safety, as far as the isolation of the recesses is concerned; but on the other hand, if it is assumed that the distributed magazine—like its competitor—is subjected to the contiuuous aimed fire of the defence, a wide area of distribution is evidently desirable. Apart, however, from the question of distribution, Colonel Baylay's proposal is a recognition of a sound principle.



The omission of the covering mass A would add to the security of the magazine B, by removing the tamping of the most dangerous shells, and causing them to expend their force harmlessly.

V. Liability of a Gun mounted on the disappearing system to be Hit by Curved Fire.

8-inch howitzer. Range 1,200 yards. Common shell. Target a special gun portion, roofed in with two-inch wood to represent a gun-pit 17′ 0″ in diameter. The dummy—a model of the 6·6 inch gun—was raised at intervals. A shingle screen hid the position of the gun-pit. Neglecting six preliminary rounds, in which the conditions were not complied with, 16 rounds were fired, giving nine hits, of which three would have been effective. Of these, two were exactly in front of the muzzle of the dummy, and one, which dismounted the dummy, was on the two-inch wooden roof representing the steel horizontal shield. This was the ninth round fired.

Deductions. The practice was extremely accurate; but depended entirely on the observation of a range party thrown out 500 yards to the right and 400 yards to the front. The featureless plain of the Lydd range facilitated observation to a great extent, and that equally good marking would be possible under other conditions cannot be admitted. Veiled by the smoke of other guns, with which it would be confounded, the disappearing gun would have far greater chances in its favour. As regards liability to be hit, therefore, this experiment affords no conclusive data, since the conditions were necessarily unfavourable. As to liability to damage, the construction of the extemporized pit precluded all inference. It is certain, however, that an armoured interior crest and a horizontal shield would have prevented all damage to the gun and its mounting, and rendered the hits actually obtained absolutely unavailing. The thin disk of the cupola at Eastbourne was hit three times by the shells of the eight-inch howitzer, at angles of impact far exceeding that of the single hit on the wooden circle at Lydd; but the results were trifling.

It is to be noticed, finally, that the range was very short, so that as regards the probable accuracy of fire against such a target from the first artillery position of the attack, the experiment affords no evidence. Notwithstanding this, the great accuracy of modern howitzer fire under favourable conditions was strongly attested; while good observations were shown to be essential. For this reason the application of the disappearing principle in connection with coast defence doubtless offers relatively greater advantages than its employment in the armament of land forts.

VI. Protection afforded by Steel Plates against Howitzer Shrapnel.

(*a*). *8-inch howitzer.* Range 1,600 yards. Target gun emplacement protected by quarter-inch and half-inch plates of mild steel. Steel shrapnel, containing 528 bullets.

Of 15 rounds fired, seven were blind, and only two hits were obtained on the shields. These bullets *scarcely marked* the steel.

(*b*). *6·6-inch howitzer.* Range and target as above. Steel shrapnel, containing 252 balls. In 15 rounds there was one blind shell, and 13 hits were obtained on the shields. None of the balls penetrated more than their own diameter in two-inch deal.

Deductions. The failure of the 15-seconds sensitive fuze vitiated the experiment. There seems to be no doubt, however, that a quarter-inch steel shield provides ample protection against the shrapnel balls of either howitzer; while it would evidently be futile to use these projectiles on the chance of obtaining hits with the bases, or heavy splinters.

VII. Enfilade Fire against the Flank of a Provisional Work.

(*a*). *8-inch howitzer.* Range 2,400 yards. Target, a traversed flank built of loam and clay, with three gun-portions 10′ 0″ wide, separated by a 40′ 0″ and a 30′ 0″ traverse. The right gun-portion had no traverse on its outer flank. Common shell.

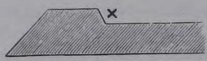
Counting the whole flank as the target, 11 hits were obtained in 20 rounds fired. No shell was blind.

The two outer guns were adjudged to have been put out of action. The effect on the flank generally was insignificant.

(*b*). *6·6-inch RML gun.* Conditions as above. In 20 rounds, 13 hits were obtained, including two shells which burst very late after graze. No gun was disabled, and only one hit was really dangerous. The damage to the flank was trifling.

Deductions. The practice was excellent and the bare statement, taken by itself, that the eight-inch howitzer disabled two of the target guns in 20 rounds, appears somewhat startling. Before arriving at a positive conclusion that guns in a traversed flank are doomed, it is desirable to look into the results a little more carefully.

The construction of the traversed flank was somewhat remarkable. Loam bonnettes 2′ 0″ high were built up on the parapet; but *ended at the line of the crest.* Thus the traverses and the parapet of the adjacent face were actually *lower* than the bonnettes, and the protection provided for the muzzles and chases of the flank guns was *greater* than that accorded to the carriages and detachments. Had these bonnettes been carried on to the rear, or had they been omitted as obviously useless, and the traverses and face been 2′ 0″ higher, the dummy guns would have absolutely escaped. The bonnette arrangement had a further disadvantage, causing the target, viewed from the firing battery, to appear thus, X being the point to lay on :—



A better mark could not well have been provided. Again, the right traverse was built of clay, and, judging from the effect of exactly similar hits on sandy loam, the damage to the right gun is greatly to be attributed to this fact alone. The immunity of the centre gun in face of an eight-inch shell, which burst on the crest of the traverse on its flank, is very remarkable.

The experiment goes to show that the dangerous area is small, and practically consists for each flank gun of a portion of the crest of the adjoining traverse. Shells striking further back, on the tops of the traverses, produced no effect whatever. The value of traverses is very strongly attested. Had they been absent, *all* the dummies would have been disabled by the howitzer; while the 6·6-inch gun, which effected nothing at all, would have dismounted two guns. There appears to be no necessity whatever for traverses 40′ 0″ thick. Half this breadth would answer. The gun-portions should be broader, the gun being kept close under the traverses, which should be revetted to within 3′ 6″ of the crest on the inner sides, and left at an easy slope on their outer sides. As to the liability of the flank of a provisional work to be hit under service conditions, there is of course no means of forming a judgment. The attacking battery at Lydd was carefully alligned on the prolongation of the flank, which would in most cases of extemporized works, and in some instances of permanent forts, be a rather difficult matter to arrange. So well were the range and conditions at Lydd known, that the very first eight-inch shell fired caught the crest of the front face of the target work at exactly the right spot, and dismounted the flank gun. If the first shell fired during a siege fell within 100 yards, it would be an exceedingly good shot.

The conditions of a flank are peculiar. Its fire is needed only for a brief period, in the case of an assault on the interval between two forts; or, at a late period of a siege, to prevent saps or lodgments being made in this interval. Thus it is never necessary to keep a flank constantly manned, and speculation as to the probable effect on men of the effective rounds obtained in the Lydd experiment is little to the point.

If the defence has permanently mounted guns on the flanks, two courses offer themselves to the attack. Either a certain number of howitzers may be told off at an early period to destroy the flank guns; or, the flank may be left alone, in the belief that it can be kept silent at the moment when its fire would be serious to the attack.

In the first case, the artillery of the attack may have enough on hand with the front fire of the defence; while a very large number of rounds would have to be fired, under service conditions, to do more damages to the traverses than could be repaired with ease in a night. As for the guns, the experiment seems to show that in permanent works they can be made quite safe against individual projectiles, so that several shells falling exactly on the right spot would be needed to disable them.

In the second case, fire suddenly directed on a flank, and required to be immediately effective, would probably fail in its object.

The increased range and shell power of field guns has obviated the necessity for permanently mounted guns in flanks; while within suitable conditions of range, quick firing and machine guns would be even more effective. Provided that the flank armament is so light that it can be run into position in a few minutes, preliminary pounding of the traverses will be a clear waste of force. The flanks of provisional works will certainly have light moveable armaments.

VIII. Sap-heads.

(*a*). *Deep sap.* 12-pr. BL. Range 300 yards. Steel common shell. Sap-head constructed of loam and protected by sandbags and a mask, according to the service arrangement. Angle of fire about 45° to line of sap.

Nine rounds were fired at the sap-head, but no hit was obtained, the slight undulation of ground sufficing to protect a mask only nine inches high; three rounds were fired at the first portion, giving one hit, which made a breach 6′ 0″ broad in the little mound; three rounds were fired at the second portion, giving two hits, which partially breached it.

Sap-head protected by Donelly's shields. Five rounds were fired, but the shields could not be hit on account of small undulations of ground, and the practice was given up. One shell hit the sand-bags, displacing three of them, and hitting No. 2 dummy.

6-pr. Hotchkiss quick-firing gun. Range as above. Special common shell. Sap-head protected by three Donelly's shields.

Thirteen rounds were fired, yielding one hit on the centre shield, which penetrated it. All the shields and three sand-bags were displaced, but no damage was done in the sap.

Deductions. The shields at a slope of 8° will not keep out a 6-pr. shell, and it becomes questionable whether they are worth employment against machine gun bullets. The difficulty of stopping the progress of an ordinary deep sap was shown; although the conditions would have been more favourable to the defence if the guns had a command over the work.

(*b*). *Single kneeling sap.* 12-pr. BL. Range 300 yards. Steel common shell. Sap-heads protected by two sap-rollers, and two Knight's shields.

All the eight rounds fired hit the sap-head, displacing shields, gabions, and one sap-roller, which was completely disabled. One shell burst in the sap.

In 10 rounds of shrapnel, seven effective hits were obtained, and the sap was thoroughly searched by the balls.

Deductions. Even if the management of two sap-rollers was practicable, this sap is evidently impossible in face of the 12-pr. BL gun. It was shown in 1884 that the sap-roller was useless against the 6-pr. quick-firing gun. The Germans abandoned sap-rollers about 12 years ago, and regard deep sap as the only possible method of advancing. It is certain that, if the defence makes use of field or quick-firing guns, all other methods are now impracticable during daylight.

IX. The Destruction of Abattis and Entanglements.

6-pr. Hotchkiss quick-firing gun. Range 400 yards. Abattis and entanglement. Steel common shell.

The obstacles were unprotected; 10 rounds were fired, of which six were blind.

Deductions. The experiments afford no positive data. The 6-pr. is about the last gun which would be employed against such obstacles, which are, moreover, generally protected to some extent. To shoot at an abattis with this gun would be nearly equivalent to trying to cut down a thick hedge; while the number of projectiles required to clear a moderate area of entanglement would be outrageous.

Miscellaneous.

In addition to the above experiments, an exterior slope protected at the toe by railway bars was attacked by the six-inch BL gun. The parapet was of clay, with a one-foot covering of sand. The rail protection was cleared away in 21 rounds, and the breach was half completed in nine rounds. The value of even this small layer of sand proved considerable. The rails were broken and thrown over the parapet. If rails were available for this purpose, it would be much better to form them into a similarly inclined layer buried in the parapet.

The 0·6-inch wall-piece was tried against various shields, but the results are unimportant. The advance in machine guns has killed this weapon.

Trials of shells charged with guncotton, blasting-gelatine, and metadinitro benzol (Grüson compound), tend to show that against earthworks very little advantage over powder is gained. The two last-named explosives proved the most powerful, but the third shell, charged with gelatine, burst the howitzer in which it was fired. Though Mr. Nordenfelt has succeeded in firing 6-pr. shells thus charged, it is clear that the danger of using this explosive has not yet been overcome. The metadinitro benzol shells are as ingenious as they are complicated and expensive; but they burst well, giving only one blind in 20 rounds. The wet guncotton shells are doubtless safe in themselves, but the trials were most unsatisfactory, giving 13 blinds in 20 rounds. Unless greater certainty of burst can be assured without loss of safety, these shells evidently have not reached the stage of adoption.

It is to be observed that the want of increased effect against earthworks by no means reduces the importance of shells carrying high explosives. For the attack on sunk scarps, caponiers, and flanking chambers, such shells will be specially valuable, and for this reason the Germans have devoted much attention to the subject. Moreover, a powder-charged shell striking a bank at a moderate distance in rear of a gun, tends to throw back few splinters. Striking a thin wall, the pieces all go forward through the breach formed. In the case of a shell carrying a high explosive, a considerable backward effect may be expected under these circumstances, while the very large number of fragments* given off will impart something of a shrapnel character to the burst.

* Of one guncotton shell 550 pieces were recovered; of one metadinitro benzol shell 779 pieces.

Iron wire netting, 12 B.W.G., one and a half inch mesh, was tried as a protection for the parapet against blast, and, under full charges from the eight-inch BL gun, failed completely. There seems every reason to expect, however, that when the proper strength of wire, size of mesh, and mode of attachment has been arrived at, this method of protection will answer. The matter is one of great importance in connection with the parapets of coast defences.

General Conclusions.

The principal fact brought out by the experiments of 1885, is the value of sand or light soil for parapets. It is a lesson more than 20 years old. General Gillmore, in his report on the siege of Charleston, stated :—

"*The penetration of rifle projectiles fired into a sand parapet, standing at the natural slope, or nearly so, is but trifling. They are almost invariably deflected along the line of least resistance, or one departing but slightly from it, scooping out in their progress a small hollow, the contents of which are scattered but a small distance. Under such circumstances, the general effect produced by firing a large number of successive shots within a small area, of say from 15 to 20 feet square, is by no means commensurate with the necessary expenditure of ammunition.*"

Alluding to the experience gained at Fort Wagner, he further remarked :—

"*The powers of resistance of pure compact sand to the penetration of projectiles very much exceeds that of ordinary earth.*"

"...... *pure quartz sand, judiciously disposed, comports itself unlike any other substance, and for certain parts of fortifications its peculiar properties suggest its exclusive use in preference to ordinary earth.*"

Like many another lesson of the great American War, this has required to be re-taught. The great practical experiment carried out at Alexandria served to confirm General Gillmore's view in the fullest sense, and now that it has been shown at Lydd that the new rifled guns are relatively less effective against sand than those of older type*, it may be expected that the fact will receive practical recognition.

All parapets in front of permanently mounted guns should be made of the lightest available soil. A layer of sand 2′ 0″ thick will

* In reporting on the results of the bombardment of the Alexandria defences, the writer stated : "For dealing with earth parapets generally, it is possible that the new guns may prove to be even less effective than the existing ordnance."

prove a most effective protection. In some cases, vegetation sufficient to maintain the sand surfaces against the effects of wind and rain, can be counted upon. In others a thin top dressing of earth may be needed.

To increase the thickness of the parapets of coast works beyond a certain point is evidently useless. It is essential that no projectile striking the exterior slope should be able to trench through the parapet; or, by bursting after the small penetration attainable, to breach it. To provide a greater thickness is a waste of labour, and to build infantry parapets 40′ 0″ thick is manifestly absurd. Bearing in mind the behaviour of projectiles in light soil, the standard of ideas as to what constitutes "bombproof protection," needs revision.

For the rest, the results obtained at Lydd must be received with extreme caution. As Captain Main, R.E., has indicated, a study of the sieges of 1870–71 is essential before any estimate of the corrective factor can be formed. This is specially necessary in reviewing the practice at unseen objects. The excellent shooting of which the eight-inch howitzer is capable needed no further illustration; but the practice depends absolutely upon observation. At Lydd, in nearly every instance, the result of each shot was telephoned back to the firing point. In other cases, well-placed and trained observers marked the fall of the shells. When a work is under fire and firing, it is not easy to see how the projectiles of a particular gun are to be identified, even by experts; who, moreover, are little likely to be available. And it is as well to remember that two experts, possessing almost unique experience, have been known to independently underestimate the fall of a shell by 500 yards in 2,000.

London, 5th August, 1886. G. S. C.

PAPER VII.

INVISIBILITY.

By Capt. G. S. Clarke, R.E.

The defences of Alexandria possessed only two advantages: they were constructed mainly of sand, which turned up the heavy projectiles of the attacking ships, and many of them were comparatively invisible. This latter characteristic was pointed out in the report on the results of the bombardment, where invisibility was contended for as one of the most important conditions to which the coast defences of the future should conform. It may now be useful to discuss the subject more fully, and to seek to show how far this condition can be fulfilled under different circumstances.

At starting, it is fully granted that at short range, where the details of a work and the position of shore guns can be clearly made out, such invisibility as can usually be attained matters but little. Captain Lewis, R.E., in the Appendix to his able Lectures, reiterated his opinion that "ships attacking a properly built and manned fortress will fight at short ranges." It is not easy to see why, when worthily opposed, ships should adopt tactics for which they have shown no preference in attacking weak and badly manned defences; and it is certain that mines, of which ships are not indisposed to take account, will in many cases prevent close quarters, while it is clear that the policy Captain Lewis regards as absolute will provide golden opportunities for the torpedo boat. Accepting his dictum, however, as the rule of the future, exceptions will unquestionably occur in which the advantages claimed for invisibility will have full scope. All naval commanders are not equally daring. Lightly armoured vessels may have to engage coast defences. Injuries inflicted, say in an attempt to force an entrance into Port Philip, Victoria, 9,600 miles from Toulon and 5,000 miles from Vladivostock, would not be lightly risked. Mines and difficulties of navigation may combine to prevent an enemy from following the obsolete and now utterly erroneous maxim of 'reserving his fire till he can see our eyes.' Coast defence batteries will certainly not defer *their* fire till the ship is at close quarters, and the ship herself may possibly be tempted to reply. Under these circumstances, it is still worth while to consider how far we may protect our works, present and future—the more so as this sort of protection, at least, costs little.

The object in view is so to disguise coast defences that their design may not be patent to the most casual observation ; and secondly, to render the individualizing of the guns of the defence as difficult as possible. Granted that the plans of our defences and the positions of our guns will be known to all the world ; still the practical advantages of invisibility will be none the less marked. There may be a perfect map of Malta in the Captain's cabin ; but if this has to be translated to individual members at the ship's guns, in the heat, smoke, and confusion of an action, its value will be heavily discounted.

Another important fact, re-attested by the action at Alexandria, is that in order to permanently silence coast defence guns it is necessary to hit them. Every gun disabled by the fleet was fairly hit ; and of all the guns mounted in accordance with other than mediæval ideas, there was but one case of independent injury to carriage or platform, sufficient to cause permanent disablement. In the case referred to, the gun—never in action—was taken in reverse, as might reasonably have been expected from its position. It may, perhaps, be laid down as an axiom, therefore, that guns mounted in good earthworks must be individually hit in order to place them *hors de combat*. The cases of guns mounted close under high buildings, such as the Pharos Tower at Alexandria, the Europa Lighthouse at Gibraltar, or half-a-dozen well-known instances at Malta, obviously do not fall into the above category. Such guns may be seriously disabled by projectiles which ought to be recorded as "5,000 yards over." In other words, the vulnerable target need be little larger than the breech section of the gun. Theory will doubtless prescribe that in attacking barbette guns, ships should invariably cross fire, so as to obtain a broadside target ; but human nature is sometimes opposed to theory, and there may be expected to be a considerable tendency on board the ship to fire at the particular guns which are hulling her, rather than to leave them to the chance ministrations of a distant consort, who is only too likely to be imbued with a similar prejudice.

The clear moral of it all is that anything which can be done to render laying on a particular shore gun less easy must be a definite gain to the defence. Study the appearance of various works, as viewed from the sea, and the difference will be found to be enormous. Given suitable conditions, the guns will be barely distinguishable with a field glass on a clear day at 2,000 yards; seen *en silhouette* against the sky, or a contrasted background, they will be clearly visible to the naked eye for six miles. The great Krupp gun in the Dardanelles frankly announces its presence by appearing as a black bulls-eye on a bright white ground. The 100-ton gun in Cambridge Battery, Malta, requires a practised eye to find it, and might be made almost invisible. The 38-ton gun in Harding's Fort, Gibraltar, is pointed out with eager pride by every tourist on board a P. & O. steamer. Its fellows at Hatherwood Battery, Isle of Wight, are in certain lights altogether invisible. The difference would apparently exercise a marked effect on an action.

The difficulty of maintaining a complete general direction over the fire of a ship—more especially if in motion—is very great. A highly trained officer, with nerves of iron, may, perhaps, be spared to lay each turret; but the majority of the guns on board an ironclad must be laid by gunners, who will not always adopt a severely scientific view of the object of their fire, and who will frequently—as at Alexandria—show a weakness for a good upstanding target, indeppendently of the probable advantages to be gained by hitting it. If, to such, you can say, "fire at that particular gun only," it is a clear gain. If you must amplify your directions—"fire a little to the right of that brownish bush; not the bush nearly on a line with that low tree, but the one which is almost directly above that triangular piece of bare grass; there is a heavy gun there, and you will see the flash in about two minutes"—there are evident elements of error. Suppose the ship to be under weigh, and the relative positions of things changing every minute; try to imagine the disturbing influences of an action; remember the natural tendency of the average No. 1, when his gun is loaded, to let it off without waiting for a nice discrimination of particular bushes, trees, or other objects; finally, reflect that the officer cannot be always at hand to see where the shot goes, and it will be granted that this translation of the field-glass observation of the gunnery lieutenant to the gunner's unaided eye may not invariably secure literal obedience.

It is proposed to consider under several heads the conditions by which comparative invisibility may be obtained in coast defences present and future.

Background.

A hill rising gradually in rear is always advantageous. Such a background will not serve to record errors of excess in range, but will materially aid in disguising works of defence. If, on the other hand, it is barren and rocky, and the parapet of the work is a bright band of well-trimmed turf, as in some existing cases, the gain will be minimised. The object should be to assimilate the work to the background. If the latter is rough, let the former be rough ; if the hill in rear is bush-grown, plant the parapets similarly, and leave them to nature.

Guns should never show against the sky. Failing a hill background, therefore, plant trees or tall bushes, building a bank, if necessary, for them to stand on. If no vegetation will flourish, a rough wall, high enough to appear just above the guns at moderate ranges, and not too near so as to give back dangerous splinters, may be employed. Such a wall can be washed with any suitable colour. Mere canvas screens or wooden hoarding, coloured at discretion, might be temporarily used for the same purpose. There can rarely be any excuse for turning a gun into a beacon ; and to provide (as at Inchkeith and elsewhere) a white concrete ground on which to place a black gun is to concede an unnecessary advantage to the attack.

Form.

The form adopted in the design of a work will exercise a determining influence on its visibility. Rectilinear contours and models have been the curse of coast fortification. If a design is made with straight line contours and sharp angles, the tendency in execution will be towards extreme fidelity. Profiles will duly be erected, and the result will be a structure like Fort Madalena, Malta, or South Hook, Pembroke, plainly labelled—" This is a Fort." Curved contours are now being employed, and it is generally recognized that great latitude must be granted to the constructor. Let him avail himself of it to the fullest extent, remembering that his contractor is almost certain to exhibit a preference for straight lines and angles. The measure of excellence in a model will usually be its neatness. Hence the model too often shows all the charateristics which a coast work should *not* possess. Ideas once formed are difficult to uproot, and the same species of mental demoralization which results from a continued contemplation of obsolete guns, may be engendered by a model in itself a work of art.

As a general rule, therefore, interfere with the near foreground of the guns as little as possible. Sink batteries in preference to building them up. The presence of a gun at Buena Vista Site, Gibraltar, is advertised by the artificial mass built up on the top of natural rock. By leaving nature unimproved this gun might indeed have been invisible.

Abrupt changes of slope are invariably conspicuous, especially in sunshine. Since nature abhors straight lines, avoid a long straight crest above all things; it is never necessary—since a level row of guns, except in a saluting battery, is a thing of the past—and it frequently adds to the cost of a work by entailing unnecessary earth-movement. All geometrical forms are objectionable, as, for example, the carefully shaped cones, frequently formed with misplaced accuracy in front of salient guns. By omitting grading, and by planting, all such obviously artificial forms can be broken up and visibility avoided.

The flanks of a coast battery also require special treatment. The exterior slope, seen in profile, frequently proclaims a fort for miles. Its outline can be broken without any difficulty whatever. Traverses rising above a parapet, with their side slopes showing sharp in profile are always to be avoided. At Fort Madalena, Malta, there is a solitary traverse of this description, on the long sea face, conspicuous enough for the leading mark of a ship channel. There is no real inconsistency in maintaining the interior of a coast battery as neat as an artillery store, and leaving the exterior to nature. An exterior slope cannot be used as a tennis ground, and by abandoning the lawn ideal which is still upheld in some cases, invisibility will be promoted.

Colour.

The colouring of the guns is a highly important point. Black will usually be the worst colour that can be adopted; especially if, as is generally the case, it gives off bright reflections. A dull mat colour is always desirable, but the tint should be varied to suit individual conditions. The dull white applied to the 100-ton guns at Malta is remarkably successful against the uniform whiteness of the background. It might be supposed that Malta offers conditions unfavourable to invisibility. The very reverse is the case. At Gibraltar, however, the background and surroundings of the 100-ton guns are brilliantly green in spring, and a greenish brown in the late summer and winter. These guns should be painted a greenish brown. The tint, in every case, should be rather lighter than the average depth of colour of the setting. Uniform flat washes are in nature only to be found in skies, and English lawns, scarcely even in calm coast waters, which are generally heavily loaded with reflections. Guns should be spattered, therefore, rather than treated with a flat tint. However untidy their appearance may thus become, they can be kept equally serviceable, and will shoot none the worse. The glitter on a bayonet is no evidence of its temper, and, when fixed to a rifle, it proclaims the bearer for miles.

Cement concrete has, from the present point of view, been the bane of the Engineer. A wall built of the stone of the country soon oses its visibility, weathering down to a mellow hue, and, where it is not expensively pointed at intervals, clothing itself with a rich garment of lichen. Hard rendered surfaces of cement concrete weather little, look like nothing in nature, and proclaim in terms not to be mistaken that the Engineer has been at work. Even at Malta, an island of white stone, concrete powerfully asserts itself, and insists on being seen.

In another case, a recent cartridge store with clean concrete surfaces stands out from a background of dark rugged rock, and can be seen for miles. This is as it should be, in the case, say, of a monument; but does not fulfil all the requirements of a magazine of explosives turned towards, and within 2,000 yards of an enemy's possible position.

Devil's Gap Battery, Gibraltar, again, is a white concrete wart on the grey-green western slopes of the Rock. In this special position, it is hardly too much to say that a regulation blanket would be a better protection than this advertisement in concrete.

Bonnettes of stone or concrete are rarely satisfactory from any point of view. When, as at Fort Lenardo, Malta, they have *vertical* faces rising *eight feet* above the crest over which the guns fire, they stand condemned as being simply an artificial mode of increasing at considerable cost the dangerous target offered to a ship's fire; while in most cases they add materially to the visibility of the guns whose detachments they are designed to protect. At Victoria emplacement, Gibraltar, on either flank of the 100-ton gun there is a trapezium of glaring white concrete slope, set in a luxuriant growth of vegetation. If the great gun could be rendered absolutely invisible by any process of enchantment, these slopes would serve to show an enemy's No. I. exactly where to aim. To bisect the distance between two closely adjacent, sharply outlined, symmetrical targets, is an even easier process than laying the sight directly on an object less well defined. If these objectionable slopes had any protective value, their presence would be partially excused. As it is, they are shams—mere screens a few feet thick with no mass behind them. Earth would have been positively less dangerous to the gun, apart from the fact that invisibility would have been secured by its employment.

Concrete can be darkened by an admixture of soot; which, however, if introduced in sufficient quantities to produce much result, would materially diminish its strength. It can be tarred and sprinkled with earth or sand, much of which would soon wash out in a rainy climate, and leave a surface which would gleam in the sun like a looking glass or a slate roof. If painted, the oils sink in and leave a nearly indelible stain. But here also flat tints are inadmissible. Blotching with a large brush is required, which will not merely lower the tone to any desired pitch, but will break up the flatness of the surface, obviate uniform reflection, and secure assimilation to any surroundings. Concrete not rendered weathers to some extent, and soon becomes less glaring.

Granting—for the purposes of the present argument only—that it is necessary to carry up the concrete mass covering a gun emplacement to the plane of the superior slope, the effect is usually a glittering white line, directly under the muzzle of the gun, broadening in proportion both to the depression provided, and also—within limits—to the range from which it is viewed. Here again, artificial colouring can be resorted to with excellent results, although, as will be noticed hereafter, vegetation may in some cases be even more effective.

Foreground.

The railway embankment treatment of parapets has been already pointed out as undesirable; it remains to deal with the question of the foreground in advance of the so-called "exterior slope"—a term which might with advantage lose its literal accuracy in connection with most defence works.

The ditch constitutes, in some cases, an effectual advertisement of a fort or battery. There will be another straight defined line drawn parallel to and under the crest. Perhaps the top of the scarp exhibits a broad band. At the Needles battery the ditch is visible for miles. At Newhaven even the flanking arrangements are frankly exposed, and there is a caponier generously posing as a target. At Rinella Battery, Malta, the ditch helps to tell the tale. As Colonel Schaw has lately pointed out, the divorcing of the ditch from a too rigid alliance with the parapet is no new proposal; but Choumara has at present found few apostles in England, where we have perhaps been unnecessarily generous in the matter of excavation. We have ditches with virtual precipices a short distance in advance of them; others, again, closely following the edges of cliffs. Carlisle Fort, Cork Harbour, has a ditch of monumental proportions, which is said to have been the grave of the fortunes of successive contractors. A part of this ditch serves to enclose a narrow ridge at the top of a natural cliff, and gives rise to the probably unique phenomenon of a piece of infantry parapet facing the sea suddenly changing into one facing the other way, without any alteration of alignment. Some ditches seem to be built up much on the Hibernian plan of casting a gun—"you take a hole and pour molten iron round it." No. 2 battery, Inchkeith, has a land front ditch, duly flanked; but there is nothing to prevent a whole ship's company walking up the natural slopes in front of the work. Breandown, Severn defences, has a well-flanked gorge ditch; but almost any old woman could walk into the work from the front. Fort Langton, Bermuda, a little bit of a work, has six flanking chambers, and only just escaped having twelve. A commanding officer, not desiring to have two-thirds of his little garrison permanently quartered in the ditch when danger threatened, would be likely to block up the entrance galleries tightly, and leave the ditch for the enemy to get into—if he liked.

In advance of the ditch, we have perhaps a long graded glacis, sometimes—but not always—a legacy of the days of the "percussion musket," or flint-lock. All these things make for visibility. Progress, the breech-loader, and the machine gun, will simplify the task of the designer aiming at concealment. Accept the necessity for a ditch, even if unflanked, and the glacis beyond may be left to nature. Where guns are on a steep bluff, a little scarping here and there—not a regularly traced line—combined with iron fraises or palisades—not necessarily continuous—will frequently be considered amply sufficient protection against a few boat parties, who after all are composed neither of Alpine climbers nor monkeys, and who, even if they succeeded in reaching the parapet, would now-a-days be easier victims than the gallant Spaniards who escaladed the back of the Rock of Gibraltar. If the Russians on Mount Nicholas, in the Shipka Pass, without ditches, flanked or otherwise, could repulse the brilliant attacks of the Turkish infantry, latterly with stones, we with machine guns may count on equal success against an enemy's blue-jackets.

Thus the problem of invisibility will be simplified. Parapets may in many cases be effectively masked by trees. At Oscar Friedricksborg Fort, the main defence of the channel of approach to Stockholm, this plan has been adopted with wonderful success. There is a high barbette battery commanding the water approach. Tall pine trees, standing on what might have been termed the glacis, and spoiled accordingly, rise to the level of the muzzles. Viewed from the sea coast side, it is almost absolutely impossible to identify a single gun. Yet the fire is not in the least masked, and in the worst case the shells of the defence would easily tear their way through the light branches. It is true that there is a venerable legend to the effect that a projectile was, 'once upon a time,' turned up by blades of grass: but rabbits are not infrequently shot through grass, and even swede-tops, so that there is hope for modern shells opposed by pine needles. All the minor defences of the Oscar Friedricksborg position are equally well concealed. There are several other batteries among the trees which defy detection. Under the ordinary conventional treatment, they would have been magnanimously proclaimed from afar.

Prominent Objects.

High chimneys, flagstaffs, or other well defined and prominent objects in the neighbourhood of guns, are to be avoided. Within limits, indirect laying on board ship is just as easy as any other mode of aiming, and such objects greatly facilitate it. At Alexandria the positions of the magazines were usually indicated by tall lightning rods, which, being in many cases innocent of any proper earth connection, were doubly objectionable.

Disappearing Guns.

The disappearing mountings, which it is hoped will be provided for some of the new B.L. guns, will enormously facilitate disguise. Under most circumstances, there appears to be no reason why the positions of guns thus mounted should ever be identified, except by the flash, which is not an easy thing to lay upon. But much will evidently depend upon the design and construction of the works in which they are to be placed. At Flatholme, Severn defences, the pits for the 7-inch Moncrieff counterweight guns are exceedingly well masked.

Similar concealment has not always been accorded to disappearing guns. In the middle of the Corvadino Lines, Malta, there are two counterweight pits, built up high above the level of the crest line, and the most conspicuous objects in the neighbourhood. It seems hardly fair to *build up a pit*, as we have done at Popton and

Hubberstone, and as the Egyptians probably intended to do, when they mounted their 9-inch counterweight gun on the open sea shore. The Corvadino Lines have the compensating advantage, however, of hundreds of yards of infantry parapet, 32 feet thick. At Newhaven Fort one of the 9-inch counterweights is placed in what is virtually a circular stone tower of vertical cylindrical form.

The dummy disappearing gun, employed in the Portland experiments last year, raised itself out of a stretch of natural down land. When this dummy was in the loading position, there was nothing whatever to indicate the site of what was thus a veritable *pit*; which partly accounts, no doubt, for the fact that the effect of the fire of the attacking ship was practically *nil*. Nevertheless, the conditions at Portland were not ideal; since, when in the firing position, the gun showed against the sky, while there were no scattered bushes which might be mistaken for it. The flag on the top of the splinter-proof sheltering the range party was officially reported, however, to be so remarkably like the dummy, that it was liable to be fired at.

Existing Works.

Very much may be done, at small cost, to diminish the visibility of existing works. The armour belt of Spitbank Fort has been painted in black and white chequers with admirable results. The ports which used to be bulls-eyes are now indistinguishable, and the prominent mass of the fort is reduced in tone. This treatment appears suitable to all such continuous armoured casemates, the colour of the chequers being varied, however, to suit the prevailing tint of the coast line. It has been suggested that by a little vigorous scene painting, a casemated battery can be assimilated to a rocky coast. Fort Delimara, Malta, would be a good subject for this treatment. It is a shielded battery, with massive concrete merlins between the ports. Standing above and by the side of a naturally weathered cliff, the Delimara guns offer as good a target as the captain of a gun's crew could desire to lay upon. The judicious application of a big flatting brush would change all this. The casemates at Camden and Carlisle lend themselves to similar treatment.

Where trees and vegetation flourish, very much can be done by well-considered planting, both in front and in rear of the guns; while the painting of the latter in accordance with the principles advocated will materially aid in disguisement. The guns in Kinghorn battery, for example, could thus be almost obliterated.

Concrete slopes can be painted, or a rough rubble wall can be built in front of them, and vegetation fostered. This, in the case of Devil's Gap Battery, above alluded to, as well as in that of several other works at Gibraltar, would promote invisibility to an unexpected degree. Screens of cork bark in front of guns have been suggested, and appear to be worth a trial. Creepers deserve every encouragement, and ivy is invaluable. These are but a few ways in which the prominence of our defences can be diminished, and a study of individual works from the point of view of the attack—not from plans—will not fail to suggest others.

Invisibility will possibly produce a loss of moral effect, "Frowning batteries," will cease to be a term dear to poets and newspaper correspondents; but, if it is the case that the mere appearance of his target is a matter of serious importance to the Wimbledon prizeman, the relative visibility of shore guns may be expected to exert a determining influence in an action. It would be better, perhaps, if some defences did not "frown" quite so much.

All experience goes to prove that the appearance of the target proffered to the ship does actually exert an enormous effect on the accuracy of her fire. Concealment is thus a very real protection, none the less valuable because it is not to be measured in feet and inches.

There is nothing new under the sun, and no originality whatever is claimed for the views here advocated. It is occasionally desirable to re-state an ancient case.

London, 15th July, 1886. G. S. C.

PAPER VIII.

SEMI-PERMANENT INFANTRY REDOUBTS.

By Major G. R. Walker, R.E.

It having become desirable to design works of a semi-permanent type, which might be constructed in a short time, to occupy positions for which permanent works, though designed, had not been commenced, or where something less than permanent works were considered to be sufficient to meet the necessities of the defence, it was decided to seek for the solution of the problem by the construction of purely musketry redoubts, commanding at close range batteries of siege type in which the defender's guns should be mounted.

The conditions to be fulfilled were considered to be:—

(*a.*) The greatest possible development of musketry (including machine guns) fire from the redoubts, combined with the best possible obstacle to assault, efficient cover for the defenders, and the minimum of exposure of the work to distant view and fire.

(*b.*) The maximum amount of protection for the batteries outside, both by musketry fire from the redoubts, and by the provision of an obstacle sufficient to protect them from assault.

The fulfilment of condition (*a*) was sought for by—

(1.)—Tracing the redoubt in the form of a long and narrow oblong, with the corners rounded off; the length, in any particular case, to be adapted to the proposed garrison; the whole of the parapets, unincumbered with guns, being available for musketry fire; the width so designed as to afford, in plan, as small a mark as possible to the enemy's fire, while allowing sufficient space for the bombproofs required to shelter the garrison. The section given in the *Plate* shows the least depth that is considered suitable. The cover for the garrison, constructed as shown beneath the parados, is primarily intended for the shelter of the men in action, but it also affords cover from the inclemency of the weather. In winter the casemates may be temporarily closed in rear with any materials which are available, and stoves might be added; but no attempt has been made to provide permanent barracks fitted with all the requirements of civilization. The troops would, as a rule, live in tents, or otherwise, outside the work, in rear, and the work need only be fully manned when attack was anticipated; and as for such a position an outer reserve would be indispensable, this arrangement would present no difficulty.

(2.) The profile is arranged so as to get rid of all dead spaces in the ditch, and to bring the material obstacle to assault under direct fire from the parapet, while effectually covering it from the enemy's artillery fire. The section will show that this is done by prolonging the superior slope of one-sixth to the front (in the form of a glacis), until it reaches a depth of about ten feet below the natural level of the ground, and by placing in the ditch thus formed an iron palisade, leaving the counterscarp at the natural slope of the earth, and constructing a small glacis to increase the cover for the palisade. Inside the work there is good shelter behind the front parapet. The parados, which is of the same height as the crest, and has a gentle slope in front, affords cover to the bombproofs, which are protected against high angle fire, with iron rails, two feet of concrete, and about five feet of earth; the rear parapet is kept as low as is consistent with its obtaining a view of the ground in rear, in order to make the most of the protection afforded by the parados.

The command of the whole work is reduced to the minimum, consistent with the defence of the ground in front by musketry fire, with the object of rendering it as inconspicuous as possible.

The fulfilment of condition (*b*) includes—

(1.) The protection of the batteries by the fire of the redoubt. On this point it is only necessary to say, that their defence, supposing the maximum development of musketry fire from the redoubt to be attained, depends solely on the full exposure to fire from the redoubt of the batteries themselves, and of the approaches to them, and is therefore simply a case of judicious adaptation to the ground for any given site.

(2.) The protection of the batteries, by means of an efficient obstacle, against sudden assault, seems to be of sufficient importance to demand, not only the preparation of field obstacles, as far as may be possible, when the necessity for defence arises, but also the extension in front of the batteries of the iron palisade proposed for the redoubts, and this more especially in positions where natural obstacles do not exist, and the means of creating abattis, etc., are not at hand.

A design for the occupation of a given position at one of our fortresses has lately been prepared on the principles sketched above. and has been partially carried out, and as the matter has excited some public attention, and been made the subject of comment, both in the public press, and also in the Corps Journal, a description of the work and of its construction may be found of interest to the Corps.

The position to be occupied is on the left of a line of defence, where it rests on a large river, forming a secure flank, the ground selected for the site being a tolerably well-defined spur running down close to the river, and about at right angles to its direction. The frontal space available is about 600 yards, and the ground in front of the position is open and well exposed to fire. For this position, the approved design takes the form of two distinct musketry redoubts of the form described above, and of sections similar to the typical one shown in the *Plate* attached. Each of these redoubts is completely surrounded by the iron palisade which forms the chief material obstacle to assault, and commands a full view of the ground on all sides, including the ridge about 400 yards long between them, upon which both can cross their fire. In rear of the crest of this ridge it is intended to cut out of the natural ground the batteries for the heavy guns which may be required to oppose the enemy's siege batteries. The guns are intended to fire just over the natural crest, the artificial parapet being reduced to a minimum for guns, and being altogether absent in the case of howitzers. The fall of the ground to the rear of the ridge is suitable for this construction, and batteries thus formed will be quite invisible, and in the duel between them and the besieger's first position batteries the latter will only have the advantage of the knowledge of the probable positions on plan occupied by the defence batteries. In order to secure these batteries from assault, the front ditches of the redoubts are connected by a similar ditch, with iron palisade all along the front of the batteries, this ditch being defended by musketry fire from the flanks of the redoubts, and from trenches between the batteries. The batteries are thus only assailable by parties passing round the flanks of the redoubts, and taking them in rear, as long as the palisade remains intact, and it is thought that it will be very difficult to breach it. On this point, however, experiments are being carried out this year at Lydd. The group of works is designed for a garrison of half a battalion of infantry, exclusive of the men required for working the heavy guns.

Such being, in brief, the design, it was decided to have the left redoubt executed by civil labour, as an experiment to determine the possibility of getting such works thrown up, on an emergency, by civil contractors, with but very slight supervision from the Royal Engineers; the supposition being, that a large number of hasty defences might have to be erected simultaneously, when, owing to other contingencies, but few officers would be available to superintend, and there would be no soldiers to execute the works.

The contract for the redoubt was given to the district contractor, the conditions being that the work was to be completed in one month from the date of giving the order. The iron palisade was supplied directly from the makers, Messrs. Morton and Co., and the rails for covering the bombproofs were provided by the War Department.

The work was commenced in June last, and was completed according to contract in exactly 31 working days, the men worked in two reliefs of eight hours each, and about 150 per relief was the maximum number employed on the excavation, of which the bulk of the work consisted. The bombproofs were completed on the 21st day.

Without going into details, it may safely be asserted, that the work could certainly have been constructed in 21 days, if not in a shorter time, but to ensure this being done by a civil contractor, a large bonus will have to be paid, as the cost of the work increases very rapidly with the speed of execution.

The contractor, who took the job at a lump sum of £1,800, states that he spent £2,300 in wages alone, which excess was due to the high pressure at which the work was carried on. The greater part of the work was done with hand-barrows, horses and carts being used to a small extent, but no steam-power.

Time was lost by not carrying out the excavation simultaneously on the whole circuit of the redoubt, but to do this would have necessitated shifting some of the earth twice, and would therefore have caused extra expense, which, from the contractor's point of view, was undesirable; in times of real emergency, the way to get such work done rapidly would apparently be to increase the rate to be paid in a high ratio for every day saved.

Looking at the section, it seems possible to complete the whole of the work in 14 working days.

It should be noticed that the position of this redoubt offered the greatest possible facilities for supply of materials, and for carrying on the works, as it is close to a railway station, with good road and water communication near at hand, and within a short distance there is a large town. There was also a sufficient supply of water in a well on the site, and the soil throughout was exceptionally easy.

In situations where these facilities do not exist, the time stated above might be found too short, but proper provision being made for the timely supply of stores and materials, and with efficient organization and supervision of labour, a month should be sufficient for the construction of such a work in this country in all possible cases.

If, however, a number of such works had to be constructed suddenly in one locality, the problem becomes much more difficult, and more time would undoubtedly be required, owing to the difficulty of accumulating, at short notice, the large amount of materials and labour which would be necessary.

The provision of the iron palisade would take longer than this, as Messrs. Morton took six weeks to provide the quantity required for this one redoubt.

The whole cost of such a work, as the one described, for a garrison of 200 men, may be taken roughly at £2,900, if constructed under high pressure, and at £2,250 if carried out in the ordinary time allowed to civil contractors.

The advantages which may be claimed for this design are as follows: those which belong to semi-permanent works in general, viz., comparative cheapness and rapidity of construction, as compared with permanent works, with the strategical advantages which follow, and which need not be discussed here, being already well-known; plus those which are due to the design of this particular work, the essence of which lies in the fact of the security of the redoubts from distant fire, owing to their inconspicuousness, and from the flatness of the exposed slopes, and their suitability for the development of musketry fire, combined with security from assault, which guarantees the efficient protection of the heavy gun batteries between them.

That they possess the special advantage of inconspicuousness is a fact that any officer can see for himself, it being quite impossible to distinguish the work already built, from the surrounding ground, at 1,000 yards.

The difficulty of injuring flat earth-slopes of this kind by artillery fire is so well-known as to need no argument here.

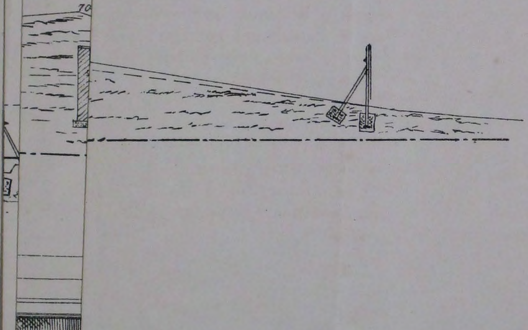
The plan of the work, and the allotment of the whole of the parapet to musketry, insures a large development of fire, while the section equally assures its effectiveness (there being no dead ground); the security against assault due to the iron palisade, supplemented as it would be, in time of war, by every device of the Engineer, may be considered very efficient, though no doubt inferior to a properly concealed and flanked escarp.

It cannot be doubted that the heavy guns mounted as proposed will be more difficult to hit than if placed in the necessarily limited well-defined space of a fort, permanent or semi-permanent, and they will be as effective; the only question then is, are they sufficiently protected? This again, in the long run, reduces itself to the old question of money *versus* men. If the works, of whatever design, are made perfectly secure against assault, the number of the defenders can be reduced, but the cost of the works, and the time required for their execution, must necessarily be largely increased. The use of works of this type will necessitate larger garrisons for fortresses than in the case of permanent detached forts similarly designed.

Whenever the ground occupied by field works is not too steep (and steep ground should, wherever possible, always be avoided), the suitability of this type of section seems to be obvious, as it gets rid of the hitherto insuperable difficulty of the defence of the ditches of field works. The semi-permanent section given in the drawing would, of course, be much too large for ordinary field works, but there would be little difficulty in designing a section, on suitable ground, for which the labour would not be excessive.

G. R. W.

7th October, 1886.



ELEVAT

PAPER IX.

THE FRONTIER RAILWAYS OF INDIA.

BY CAPT. SCOTT-MONCRIEFF, R.E.

LECTURE I.

TO THE west of the great plains of the Punjab, and parallel to the greatest of its rivers, the Indus, there lies a range of mountains, or rather a series of ranges and valleys, an offshoot from the great northern barrier of the Hindoo Kush and Himalayas (*vide Plate* I.). This mountainous country divides the plains of India from the great central valley of Afghanistan, in which lie Kabul, Ghazni, and Kandahar, and from the deserts of Beloochistan to the south. It reaches from the great backbone of Asia, "the Roof of the World," down to the coast of the Arabian Sea, between the Persian Gulf and the mouths of the Indus. This mountainous region, through which have passed from time immemorial vast armies bent upon the spoil and plunder of the rich cities and plains of India, seems destined in these modern times to become famous as one of the most important political frontiers in the world, as the place where the two great Powers of Asia are eventually to meet. It is in width about 150 miles, more or less, the mountain peaks reaching from 10,000 to 16,000 feet in height, and it is intersected by very many passes, the names of some of which are very familiar to most Englishmen. From a political and military point of view, only that part of the frontier which separates Afghanistan proper from the Punjab is of any importance; it is, indeed, the only vulnerable point on the frontier of the Indian Empire. The more southerly portion, which separates Beloochistan from Sind, need scarcely be taken into consideration.

Our attention, then, is concentrated on the Afghan frontier from Kelat, in the south, to Peshawar, in the north. Between those two points there are a number of passes, of which some four or five are the most important. Beginning at the north, we have the Khyber and Kurram routes, leading to and converging on Kabul, the capital of the country; half-way down there is the Gomal Passfrom Dera Ismail Khan to Ghazni, a pass much used by traders, but of no great military importance. Further on, there is the Thal Chutiali route from Dera Ghazi Khan to Kandahar, through the Bori Valley, by which Sir M. Biddulph's division came from Kandahar in 1879. And furthest south, there are the twin routes of the Bolan and Harnai passes, both starting from Sibi and meeting again in Peshin, beyond Quetta.

A British army engaged in active operations on or beyond the Afghan frontier must necessarily move by one or other of these passes; and the object of the frontier railways of India is either to traverse these passes, or where this is not possible, to bring troops and stores close to the mouth of the pass.

On the outbreak of hostilities in Afghanistan, in 1878, the system of frontier railways may scarcely be said to have begun, except on paper.

In the north the Punjab Northern State Railway had been completed from Lahore as far as Jhelum. This line had, up to the end of 1877, been made on the metre gauge, but in 1878 the gauge was altered to the broad gauge, 5 feet 6 inches, uniformly with other main lines throughout India. A break of gauge, which would, of course, bring disastrous confusion in time of war, was thus happily avoided. Although the line had only been completed to Jhelum, surveys and estimates had been made in 1877–78 for the extension to Peshawar, on the broad gauge.

During the campaigns of 1878–79–80, the work of constructing the line beyond Jhelum was pushed on with the utmost energy and resolution; but, for all practical purposes, Jhelum, 180 miles from Peshawar and 260 miles from Thal, the frontier post on the Kurram line, was the railway terminus during the whole of the campaigns. This, it must be remembered, was the line of communication for armies operating on two divergent lines, *i.e.*, by the Khyber Pass and the Kurram Valley, the point of divergence being Rawal Pindi. There is a first-rate military road leading from Jhelum to Peshawar, and a fair road from Rawal Pindi to Kohat and Thal, and during the war enormous trains of carts were kept up on these roads for the conveyance of warlike stores to the front, but the difficulties attending the organization of such a train were enormous. It was only by dint of very great exertion that this transport was able to cope with the quantities of stores of all sorts that poured in at the railway base; and, further, the roads got unequal to the increased strain on them, and got cut up and worn with the continual traffic. It was, therefore, of the utmost importance to push on the railway as far as possible. Before the close of the campaign the line was opened for some twenty miles beyond Jhelum, but this did not very appreciably relieve the difficulties of the ordinary cart transport.

Rawal Pindi, 68 miles beyond Jhelum, is a first-class military station and fortress, the head-quarters of a division, and one of the most important strategical points in the whole of India. It was here that in April, 1885, the Viceroy of India had an interview with the Amir Abdur Rahman Khan, of Kabul. The railway was opened to Pindi on the 1st of October, 1880, by which time the Afghan war had just been ended. The country between Jhelum and Pindi is extremely difficult, and the construction of the line there was a very troublesome and tedious job. The whole district is a tangled mass of ravines, and even using 1 in 50 as a maximum gradient, and curves of 1000 feet minimum radius, the work was not completed till, as we have seen, the campaign had been ended.

Meantime work had been going on steadily from Rawal Pindi to Peshawar, a distance of 100 miles, through a country which, although not so difficult as that from Jhelum to Pindi, is still troublesome to work in and with many natural obstacles. The ruling gradient on this portion of the line is 1 in 100, and the minimum radius of curves 1000 feet. As the work had gone steadily during 1879–80, the portion from Rawal Pindi to Peshawar was opened in 1881, with one gap at the great bridge at Attock, over the Indus. This was not finished till May, 1883, and when this was complete, through railway communication was established between Calcutta and Peshawar, from one end of the empire to the other. At Peshawar the terminus for the military route to Kabul, *viâ* the Khyber Pass, now remains. The line might be taken, if necessary, eight miles beyond Peshawar to the mouth of the Khyber Pass at Jamrud, and this could be done at any time without difficulty, if necessary. A line was also surveyed during the war, through the Khyber Pass, some 40 miles beyond Jamrud; but it is very unlikely that anything further will be done there unless the Amir wishes the work to be executed for his own advantage. From Peshawar to Kabul an excellent military road was constructed, under the supervision of officers of our Corps, during the Afghan campaign, and I hear that the Amir is very wisely keeping this road in good repair.

Previously to the completion of the main line from Jhelum to Peshawar, two branch lines were constructed, or rather begun. Of these one is from Rawal Pindi to Khushalgurh, on the Indus, a distance of some 50 miles. This is purely a military line, and was intended as a feeder to troops operating on the Thal-Kurram line. It has never been much used since it was made, for the war was over before it was opened, and commercially it has been a failure. Had the Kurram Valley been annexed, and a large cantonment formed there at a place called Shalozan, as was at that time contemplated, this branch line would have been more useful than it now is. I may mention that surveys were made for extending this line, *viâ* Kohat and Thal, 80 miles, and thence up the valley of the Kurram river. Here, again, it is very unlikely that anything will be done.

The other branch I alluded to above was at first simply for bringing in salt from the salt mines at Pind Dadan Khan, joining the main line at Lala Musa. By extending this branch, however, it has assumed a strategical value of the first importance. It has been extended throughout the country lying between the rivers Indus and Jhelum, commonly called the Sind Sagar Doab, and has been brought opposite the important frontier posts of Dera Ismail Khan and Dera Ghazi Khan. The former, as we have seen above, is opposite the mouth of the Gomal Pass, leading to Ghazni, and the latter is at the eastern end of the Thal Chutiali route to Kandahar. A military road is at present under construction on this route from Dera Ghazi Khan, through the Bori Valley, to Peshin, and will be, when finished, a most important strategic route. By this Sind Sagar line of railway, therefore, troops will be enabled to arrive from the great garrisons of Northern India, at Dera Ismail Khan, and at Dera Ghazi Khan, and proceed by the quickest route to Kandahar, without troubling the Sind Peshin Railway at all, and thus leaving it free for other work. There is another point, too, of immense importance. The desert which is crossed by the Sind Peshin Railway between Jacobabad and Sibi is by some supposed to be the old bed of the river Indus. In any case, a branch of that mighty river would in time of flood undoubtedly flow that way if it were permitted to do so. It is prevented from so doing by a great dam, called the Kusmore Bund, to the north of Jacobabad. Now, if a very heavy flood were to occur in the Indus, this dam might burst. It has stood very well for years, but still the thing is possible ; and if this occurred, the waters would sweep over the desert and cut off communication between Sibi and Jacobabad. This, in time of war, would be a most appaling disaster. Hence the supreme importance of having, in the Sind Sagar branch of the Punjab Northern line, an alternative communication with Kandahar, independent of the bursting of dams or other such mishaps.

To give a description of the works on the Punjab Northern State Railway and its branches, would occupy more time than is at my disposal; but it may be interesting to state what works there are, without going into details.

Between Lahore and Peshawar there are four enormous bridges, spanning the rivers Ravi, Chenab, Jhelum, and Indus. The Chenab bridge is two miles long, and was, at the time of its erection, the longest bridge in the world. The bridge over the Indus at Attock is one of the greatest engineering works in India. The great difficulty here was the depth and velocity of the stream. The river here rushes through a rocky gorge, and is liable to sudden floods of greatly increased volume. The height of the bridge has been made 110 feet above ordinary low-water (*i.e.*, winter) level, in order to keep the line well above floods. The highest known flood was, I believe, 92 feet, which occurred after the waters had been pent up by a landslip in the Himalayas. However, every hot season, when the heat of summer melts the glaciers, the volume of water coming down is enormous, and there is always a chance of a sudden rise. The bridge consists of two spans of 308 feet, and three spans of 257 feet. The girders, which are of steel, are so arranged that they carry a military road below, and a railway above. All the girders rest on wrought iron trestle piers, the centre pier being founded on an island, or partially submerged rock, in mid-channel. The founding of the pier on this rock was a matter of much difficulty, as it was discovered that the rock was honey-combed by the water, and it would have been unsafe to trust a great weight upon it. An oblong excavation in the rock had, therefore, to be made until solid material could be secured, and the whole filled with Portland cement concrete. The erection of the great girders across the rapid channel, and at so great a height, was also a matter of much difficulty. The staging was of wooden beams on the cantilever principle, working out from the pier, supported by timber struts and tied back by chains.

There is of course an enormous amount of earthwork in the hilly country between Jhelum and Peshawar, and there are a few tunnels.

Of these the most important are Margalla, 900 feet long, and three others some 600 feet each.

Having thus briefly glanced at the works on the northern portion of the frontier, let us turn to the very important section further south, to which I would desire in the remainder of these lectures exclusively to devote attention. This southern portion is more important, from a political and military point of view, because it lies at the most vulnerable point of the Empire, where, in event of war, all attention would be concentrated. And it is important from an engineering point of view, for the nature of the country there renders the construction of a railway a far more difficult task than it would be in almost any other part of the world.

At the beginning of the Afghan war of 1878–80, the communications were worse in the south than they were in the north. There was, it is true, through communication between Lahore and the sea at Karachi, but it was broken in two places, viz :—at the crossing of the Sutlej at Adamwahan, and at the crossing of the Indus at Sukkur. The bridge over the Sutlej has since been completed, but the Sukkur bridge is still unfinished, though it ought to be ready before long.

At the time I speak of, November, 1878, the branch line from Ruk to Jacobabad and to Sibi was then not under construction, except for a very short portion of its length; it was therefore no practical use to the two divisions under Sir Donald Stewart, who advanced against Kandahar in the winter of 1878–79. But the line had been surveyed, and it was put in hand without delay. Colonel Lindsay, R.E., was Engineer-in-Chief, and under his orders the rails were speedily laid across the desert separating Sind from the Afghan mountains. The materials were collected from every part of India, and the line advanced at the unprecedented rate of a mile a day. The arrangements for supplies, water, tools, &c., &c., were admirable, and in spite of the burning heat of the desert, casualties were few. By the month of June, 1880, the advanced terminus was established at Sibi, 133 miles from Ruk junction (*vide Plate* I.). The long and terrible march across the Sind Desert, which has been so graphically described by Sir Thomas Seaton and other writers, was thus dispensed with; and when the troops were withdrawn from Afghanistan in 1880-81, this railway doubtless saved many lives.

On the upper section of this line, which was then called the "Kandahar State Railway," surveys were put in hand and completed from Sibi to Peshin and Quetta (*vide Plate* II.). A careful reconnaissance was first made as to whether the Harnai route or the Bolan route should be chosen, and the Governor of Bombay, Sir Richard Temple, himself traversed both routes, and reported, in December, 1879, on this subject to the Government of India. The Harnai route was finally chosen, because, although it is longer than the Bolan route, it would be possible to find a line with a maximum gradient of 1 in 45 on the former route, as against 1 in 25 on the latter. This would of course make a vast difference in a line whose very *raison d'etre* is the supply of heavy stores and munitions of war to an army in the field. It was therefore decided to make the line by Harnai, though many distinguished men were against this view. Detailed surveys were made from Sibi to Garkhai on the Peshin plateau, and reconnaissances were made as far as Kandahar. It is true that the line indicated in these surveys had afterwards entirely to be altered, but it must be remembered that the work was done in an enemy's country, under pressure of war, when any line is better than none, and when men had not leisure for selecting the best possible alignment. The limiting radius of curves was then fixed at 600 feet, which still continues to be the minimum.

A beginning was made on the construction of this line in 1880. Some quarters were built for the engineers, some of the earthwork was started, one tunnel was begun. But the disastrous affair of Maiwand brought matters to a conclusion. The troops had to be withdrawn that protected the line, and whose presence alone made work possible. With the advance of the troops towards Kandahar, the working parties and the treasure had to be sent back towards India under a small escort. The marauding tribes, not slow to take advantage of any retrograde movement, were at once on the alert, and on August 6th, 1880, a massacre occurred at Kochali, at which a large number of defenceless men were butchered, and a great quantity of treasure stolen. An expedition went out after the guilty tribe some two months afterwards, under the command of Sir Charles Macgregor, the ringleaders were caught and punished, and part of the treasure recovered. But the bad effect of the raid continued for long afterwards, and indeed has scarcely died out yet.

Not long after this, in October, 1880, the British Government resolved to abandon Kandahar, and to stop all operations on the Kandahar State Railway. The line from Ruk to Sibi however continued to bear the name until 1884.

The money spent on the line up to that time was swallowed up in the war expenses, but I believe it came to about half a million sterling. For the most part this was money entirely thrown away. A good deal of work had been begun, but had not sufficiently advanced to have any permanent value; and most of the stores collected at great expense had to be sold at considerable loss.

Some three years passed away, and what little work had been done was gradually falling to pieces from want of repair. The Harnai pass resumed its former quietness, and except at little forts at intervals up the valley there appeared no sign of the British occupation. However, about the middle of 1883 the Government seems to have become alive to the fact that the stoppage of the works was a mistake. Orders were sent to the Government of India to re-commence the work in the following cold weather, and to this end a force of two half-battalions of pioneers and five companies of sappers was to be ordered to proceed to Sibi in October. An engineer officer of railway experience was to be made Engineer-in-Chief, he was to command the troops, and to have such an executive staff of officers for carrying out the works as the railway department could spare for him. Col. James Browne, R.E., was nominated for this command. Work was to begin as early as possible on the most difficult parts of the line. The old surveys made in 1879–80 would show where these difficult points were, and the consulting engineer to the Government of India (Mr. Molesworth, whose name is familiar to all engineers), would go over the line and give his advice on the subject. The work, however, was not to be called the Kandahar State Railway, it was to be known as the Harnai Road Improvement Scheme. Possibly it was hoped that by this means the British public would not notice the change of face that had been made by their rulers. This circumstance would be hardly worth mentioning but for the fact that still further to keep up the fiction of the *road*, as opposed to the railway, all expenditure on rails or rolling-stock was forbidden. Now many of the heavy works—all of them in fact—lay at a very considerable distance from the base of operations, and all stores had to be carried from that base either on the backs of camels, or (in case of heavy articles) dragged on wheels up the bed of rivers. It was the wish of the Engineer-in-Chief to lay rails at once, in a temporary fashion, as far up the pass as possible, and this might quite well have been done for at least 12 miles up the pass in January and February, 1884. But the orders of the Government would not permit him to do so, although it is a first principle of engineering to secure the best and easiest method of communication to the works, in all cases. It is probable that if permission to lay rails had been granted, a temporary line might easily have been made in 1883–4, from Nari to Gundakinduff, 18 miles, but even if it had only got as far as Kelat-i-Kila, 12 miles, the moving forward of the base to that point would have caused an enormous saving in the item of transport. It was calculated that this saving for one item alone, viz:—Portland cement, would have amounted to £30,000 in 12 months. Probably £100,000 more than was necessary was thus spent on camel transport. I mention this in vindication of the progress of the platelaying and carrying power of the line. It was not the fault of the engineers that the carrying power of the line was not utilised as it might have been.

I have seen it stated that girders and rails for the work were collected at Sibi in 1880, and were there when work re-commenced in 1883. This is not the case. The only rails found were a few metre-gauge rails, which had been handed over to the Military Works Depôt; and as for girders, there were none. The earthwork too that had been done in 1880 consisted only of a few banks, scarcely any cuttings, and certainly not one bank or cutting of any size or importance.

The troops ordered to the works on this occasion were half-battalion 1st Madras Pioneers, half-battalion 23rd Punjab Pioneers, and Nos. 4, 5, 7, 9, and 10 Companies of the Bengal Sappers and Miners. I may, perhaps, mention here the difference between pioneers and sappers, terms which in India are not identical as they are in some European armies. The unit of the sappers is the company about 100 strong, with one or two European officers (from the Corps of R.E.), and five British non-commissioned officers. The Punjab Pioneers are simply battalions of infantry of the line, who, being recruited from a caste (Muzbi Sikhs) accustomed to the use of tools and to digging, have been set apart specially for engineering works. Each man carries a tool of some sort with him, and, though they are not skilful artisans, they make very useful labourers. They are admirable soldiers—sinewy, powerful men, and very valuable as fighting material. They are not, however, so amenable to discipline as the high-class Sikh, who, in addition to his other good qualities, is a most docile soldier.

The Bengal Sappers are recruited from all the warlike castes of Northern India.

The Madras Pioneers were recently formed by Sir F. Roberts from two infantry regiments who did good service in the Afghan War. The men are recruited from the usual class of Southern India

Railways, and, though inferior physically, are superior mentally to the Sikhs of Northern India.

The officers of the pioneer regiments are infantry officers, and are not specially selected for engineering knowledge. There are no European non-commissioned officers.

By the end of 1883, the troops for the work had arrived at the scene of operations, and were distributed as follows :—The whole of the pioneers at Kelat-i-Kila, two companies of sappers at Babarkach, one company at Gandakinduff, one company at Kochali, and one at Spintangi (*vide Plate* II.).

There were many difficulties, however, in getting the work started. There were at first no directing officers of any railway experience, except the Engineer-in-Chief himself. Gradually, executive officers began to come in, one by one, as they were relieved of duties elsewhere. A batch of young lieutenants, fresh from England, were appointed as assistants, and thus the engineering staff was gradually organised. Another difficulty was the want of survey instruments. All those that had been used formerly had been sent away, and in the railway stores at Sibi there was not even a chain or a levelling staff. Many expedients had to be resorted to to lay out and stake off work, and it was a long time before an adequate supply of instruments arrived on the scene. Work may be said to have fairly begun by the middle of December.

In addition to the troops, large numbers of civil labourers came for employment. Some of these came in republican gangs, where each man got a share of the profits, and each man worked, but for the most part they were brought by native contractors, who undertook contract work at rates settled by the Engineer-in-Chief. These contractors generally made all arrangements for feeding their men, which was a great thing, as it would otherwise have been a dreadful burden to the engineers, and in some few cases they brought their own tools. As a rule, however, each executive engineer had to supply tools to the contractors in his division. It some cases water had to be supplied by the engineers. This was done by paying the contractors an extra rate, and supplying them with empty casks for the storage of the precious fluid.

Work went on without interruption from December, 1883, to the end of March, 1884, on the lower section, *i.e.*, from Nari to Spintangi. By the end of March the headings of three new tunnels, Babarkach, Gandakinduff, and Spintangi, had been driven. The Nari tunnel had been lined with brickwork. The foundations of seven of the most difficult bridge piers had been laid secure against all contingencies. An enormous quantity of earthwork, especially in heavy rock cuttings, had been finished. In one place 400 men of the 23rd Pioneers were engaged on one rock cutting for five months, working steadily every day except Sundays.

By the end of March, 1884, the weather got so hot that it was considered advisable to move the troops at once to the upper parts of the line. The 23rd Pioneers were ordered back to the Punjab. Of the remainder, the 1st Madras Pioneers were sent to Kach, and, being joined by the other half-battalion, were quartered there for the summer months. The 4th Company Bengal Sappers went to Garkhai, and the remaining companies to Mangi, at the head of the Chappar Rift, for tunnel work. The garrison at Mangi was afterwards increased by two companies of Bombay Sappers, who came from Quetta in July, 1884, and stayed till April, 1885.

Of course, when the troops moved, it was necessary to move everything else, stores, offices, tools, plant, and the whole body of workpeople, some 14,000 or 15,000. The management of this vast exodus was a work of considerable anxiety and difficulty. A sudden influx of people such as this into a desolate and barren land naturally caused a famine. Everything was eaten up, and for some days the matter of supplies was the burning question of the hour. Some idea of the quantity required may be gained when I state that 500 camel loads of food were consumed daily on the works.

Meantime events were rapidly developing in the outside world. In February the Russians had occupied Merv, and the British public began to turn their attention towards the East. The Liberal Ministry announced that in consequence of the encroachments of Russia the Quetta Railway would again be *commenced*. This announcement was made in May, the date of Lord Kimberley's despatch being 24th April. This had the effect of changing the title of our work from "The Harnai Road Improvement Scheme" to "The Sind Peshin State Railway," which title it bears to this day.

The early months of the summer of 1884 were occupied for the most part in survey work. The alignment was entirely re-surveyed and altered from Nasak to Garkhai, and great was the improvement thereby effected. Work was begun generally all along from Harnai to Garkhai in July, but unfortunately in August and September sickness, fever, scurvy, &c., broke out with such virulence that great numbers of the workmen died, and those that remained were unable to do much work. In one gang twenty-nine out of forty-two died of scurvy. All that medical skill and care could do was done, but even among the soldiers, better clad, better fed and cared for than the civil labourers, only a very few were fit for duty. At Mangi at one time sixty per cent. of the sappers were in hospital. At Kach the Madras Pioneers were completely knocked to pieces. The officers, too, all along the line fared as badly as the men. Everyone suffered more or less, and several laid up a store of fever and sickness which they have since had much difficulty in getting rid of.

Some of the troops were withdrawn during the autumn for the campaign in the Zhob Valley, and these did not return to the works. The remaining troops, except two companies of Bombay Sappers, stayed on till the cold weather had fairly set in, and they then returned to cantonments in India, much weakened by sickness.

Meantime orders had been issued to start the work during the cold weather on a very much larger scale. Several new executive divisions were formed, and work went on uniformly along the line from Nari to Chappar. Three regiments of pioneers were sent to the works, viz.—the 4th Madras, and the 23rd and 32nd Punjab Pioneers. These were formed into a brigade under the command of Colonel James Browne, R.E., the Engineer-in-Chief of the line, who was given the rank of Brigadier-General, and who had thus, in addition to his heavy engineering duties and responsibility, the command of a very strong brigade of regular troops. This giving a military command in time of peace to a Public Works Officer, though most necessary in this and similar cases, was a new departure in Indian procedure. With the exception, however, of the Brigadier-General Commanding and his staff officer (whose duties, like those of his chief, were both civil and military), the officers of Royal Engineers on the line (not with native sappers) were in every respect civil officers. They had no command of troops, and had precisely the same duties to perform as civil engineers. The R.E. Officers attached to companies of native sappers performed certain civil duties also, for which they received extra pay, but it was not found in every case that this mixing of civil and military work was satisfactory, and it is, I think, admitted that it is better to keep the duties distinct.

Work was again fairly begun on the lower section in November, 1884, but it had hardly been started when a severe outbreak of cholera occurred. Everything that could possibly be done was done to keep the camps of the workpeople clean, but these were so large, and the numbers of labourers so great, that there was much difficulty in the strict enforcing of sanitary laws. There were a few cases of cholera among the troops. Troop trains were kept waiting near their camps, ready to carry off a whole regiment at a time to a distance, if the disease should break out at any time with violence. Camps were arranged along the line to which troops might be sent. These troop trains were not required, and, perhaps, the worst result of the cholera was the stoppage of the works by the desertion of labour. All the Afghan workmen bolted to a man! The less noisy Punjabis and Sindis and Mekranis, from the coast of the Persian Gulf, stuck to their work well, as did also the Hindoos from the East. The working season on the lower section is a short five months, viz.—from November to March. The cholera epidemic effectively stopped the full swing of the work for the first month. During December a good deal was done all along the line, but in January, February, and March there were long and most serious interruptions from floods. The rainfall this year (1885) was most exceptional. Usually, the total amount for the first four months of the year is about three inches; in 1883 it was 2·28 inches; in 1884, 4·89 inches. This year it was 19·27 inches, nearly six times as much as usual. When it is remembered that twelve large bridges were under construction, it will be understood what a terribly serious hindrance these repeated floods were. The last great floods lasted from the 30th March to the 5th April, 1885, and were the cause of much disaster. Old natives said there had been nothing like them for sixty years, and certainly the flood levels were far above previous records. A terrible accident occurred on the 1st April. A heavy goods train, with two 48-ton engines, was coming up to Nari with stores, in the early morning. One of the culverts on the old part of the line between Nari and Sibi had had its foundations scoured out by the flood, and the rails and sleepers were simply hanging by the fish-plates. The train came along over it at ten miles an hour, with the result that both engines were upset and smashed, and about a dozen waggons knocked to pieces. Three men were killed, and one severely wounded. It took nearly a month to put right the damage caused by this flood. However, it is unlikely such a flood will occur again, and so the worst is known.

The troops were moved up to the cooler regions in the Gwal Valley in April. They had some difficulties on the march from wet and stormy weather, but the health of the whole brigade was excellent, only some six or eight men out of 2,000 being in hospital at the beginning of May.

The threatened war with Russia in March, April, and May, 1885, had its effect on the works. The orders of Government were to push on with increased energy throughout the hot weather at all parts of the line. A new temporary railway was begun in the Bolan. The Transport and Commissariat Departments collected large quantities of stores and followers at the mouth of the Bolan, and among the crowds of natives thus gathered together, cholera broke out in May. It spread up the Bolan with great rapidity, and spared neither great nor small, European or Asiatic. Among other victims was Captain Ewen Cameron, R.E., an officer of great skill and experience, and one whose kind and genial nature had endeared him to all who knew him.

At first the cholera did not spread up the railway works on the Harnai route, and we hoped that we might escape it altogether. About the end of May, however, it appeared and spread like a raging fire up the whole line. The work-people were panic-stricken. Many of the minor Government officials, such as clerks, postmasters, etc., abandoned their posts and fled without warning. The native clerks in one office left one day *en masse*. In spite of every care, the death-rate spread with fearful rapidity; some of the best men on the works, both European and Asiatic, fell victims. The Europeans connected with the management of the three most important sections of the work, viz.—bridging, tunnelling, and platelaying, all fell victims to disease. The bridging contract was in the hands of Mr. Sullivan, a gentleman who had great skill and experience in girder erection. He worked with great pluck and perseverance, but he was obliged to leave the works in June, and he died on his journey home. The tunnelling apparatus was worked by an American, Mr. Phillips, who had just arrived, specially for the work, from New York, who died after he had been a fortnight on the works. The platelaying was under a contractor, Mr. Baness, a man of great railway experience, who had just finished another large platelaying contract with success; he died of cholera in June. The intense heat of the weather added much to the general collapse. At the end of June the fire of disease seemed to have burned itself out, but not until in one month 2,000 men out of 10,000 had died. And the works on the lower part of the line had completely stopped; men could not be found to face the over-powering and combined force of heat and disease.

By the end of June the state of the works was the line completely finished for twenty miles beyond Sibi, for the next forty miles everything finished but rails and bridge girders, and beyond that all earthwork, with a few exceptions.

In another lecture we shall consider the general nature of the country and the works.

LECTURE II.

In a former lecture, gentlemen, I gave you a brief historical sketch of the railways on the N. W. Frontier, dwelling more particularly on the events which had happened during recent years on the Sind Peshin Railway, northern section. I propose now to give you some account of the engineering works on that railway, which was constructed under the circumstances formerly narrated.

I have selected this line among all the frontier railways for lengthy description, partly because having been there since the work was started I know it better than I do any other line, and partly also because it presents more difficulties from an engineering point of view than any other frontier line. Indeed, I may say that of all the mountain railways I have ever seen or read of, I do not know of any which on the whole presents greater difficulties. It is therefore, I think, for purely engineering reasons, if on no other grounds, a fit object for study by Engineer officers.

In the first place, in considering this line, it must be remembered that it passes in a very short distance over a very great height. It rises from 300 feet above sea level at Sibi to 6,500 feet above sea level beyond Kach, or 6,000 feet in 120 miles. Now in Europe the summit level of the St. Gothard railway is only 3,500 feet. There are railways in America, both in North America and the Andes, that rise to a greater height, but not, I believe, to such a height in so short a distance, nor with as broad a gauge (the guage of the Sind Peshin Railway is 5 feet 6 inches). Now the effect of this rapid rise in a climate like that of South Afghanistan is that the changes of temperature from the lower portion of the line to the highest are at all times inconceivably great. The natives have a proverb that owing to the existence of Sibi there was no necessity for the infernal regions. Again, on the upper portion of the line the cold of winter is positively Arctic in its rigour. The bitterness of the cold seems worse than the most severe winter in Great Britain. During the months of January and February the north wind blowing from the frozen uplands of Central Asia seems to freeze the very marrow in one's bones. When this wind is blowing, often camels and horses simply refuse to face it, and as the narrow mountain gorges often cause its force to be concentrated in violent gusts, it may be imagined what a serious matter it is for the passage of caravans over mountain passes. These facts made the carrying on of work on the upper portions of the line during the winter, and on the lower portions of the line during the summer, almost impossible. Men would not face the cold on the one hand and the heat on the other.

In addition to these difficulties of climate, there was the difficulty of working in an absolutely barren land. Everything had to be imported for the works, hardly anything could be obtained locally. Even lime and building stone were only in a very few places procurable. A few spars for building huts in the upper section was all that the surrounding country could supply in the way of timber. It is true that the Engineer-in-Chief arranged for the supply of some sleepers from a juniper forest to the north of the line, but the political authorities here stepped in and promptly vetoed this, as likely to cause quarrels among the Afghan tribes. So that even what might have been utilised in the country was not allowed to be used. All materials, tools, plant, cement, timber, and even labour, had to be imported from India or Northern Afghanistan. The variety of races employed as workmen was very great, and it was reckoned at one time that nine different languages were spoken on the works. In a barren and thinly inhabited country such as the one I am describing, all food supplies had to be brought from India, which of course had its effect in increasing the cost of labour. All stores had to be brought on camels or other pack animals, and an enormous number of these were constantly in use. There are no roads in the country, nor is it like a sandy desert where pack animals can go anywhere. There was a regular caravan path available for all pack animals, but this was often rendered impassable by floods, though it was the only means of communication. The camels were supplied to us by the Povindahs, a race of Afghan carriers who used to do the great carrying trade between Central Asia and India, and who still do a very fair amount of business. They had some magnificent camels. It may appear incredible, but many of these used to carry loads of 800lbs. up the pass. Generally a camel's load is about 400lbs. The cost of this camel transport was enormous, and unfortunately we were very dependent on it—a strike among the camel men meant a complete stoppage of the works.

When it is remembered that operations were carried on in a country which had the reputation of being peopled by a savage and blood-thirsty race of robbers, it will be admitted that, as compared with other railways, this line has a unique position in the matter of *initial* difficulties. Climate, material, supplies, transport, population, were all adverse to the work, so that apart from difficulties of engineering, pure and simple, there were great opposing forces to work and fight against. The engineering difficulties themselves were by no means trifling.

There are four parts of the line which present special engineering difficulties. The first is the Nari gorge from Nari to Babarkach, a distance of 14 miles. The second is the Kochali defile from Gundakinduff to Kochali, five miles long. The third is the Chappar rift, some three miles long; and the fourth is the summit of the pass, a portion some 25 miles in length from Mud gorge to Garkhai.

With the exception of these the remainder of the line is no way more difficult than any ordinary line through a mountainous country.

With regard to the first of these difficult places.—In the Nari gorge the Nari river breaks through the mountain barrier which skirts the desert for some hundreds of miles along the frontier. All the drainage of a very large portion of country stretching right back to the Bori and Zhob valleys to the north, in all some 24,000 square miles, is pent up behind this mountain range. The Nari gorge is the only important outlet for the waters between Sibi and Dera Ghazi Khan. At Babarkach, which is at the upper end of this gorge, three rivers join, and half a mile lower down another river, the Bheji, comes in. The turmoil of waters at this part of the gorge during a flood is quite indescribable. The combined waters force their way through the mountains by a wild and rocky gorge which ends at Nari, seven miles from Sibi. The hills there consist of sandstone, indurated clay, and conglomerate layers, tilted at an angle of about 28° to the horizon (*vide Plate* V., *Fig.* 2). They are absolutely barren. The general direction of the river is at right angles to the ridges, which are very clearly defined; the river has cut for itself a narrow gorge, leaving the mountains on both sides in a series of sharp serrated ridges. The appearance of this gorge is very wild, and it has a bold fantastic beauty of its own. In carrying the railway up this gorge, every care has been taken to avoid, as far as possible, the expensive and difficult bridge work involved in crossing and re-crossing the river. Tunnels have been made in various places, and many heavy cuttings and banks. But with all precautions, it has been found necessary to cross the river six times in the whole distance of 15 miles, and it is a matter of some doubt whether two additional bridges will not be found necessary. On leaving the station at Nari, the line does not cross and re-cross the river, but in order to save two bridges, keeps close under the base of the perpendicular cliffs, which have here been cut back *en bloc*, to allow room for the line, and with their debris afford a foundation for it. Then the line passes through a tunnel, which was driven in 1880 but not lined. In the three years which followed much of the roof of the tunnel fell in, and there were some blocks of rock loose and just ready to fall, the removal of which was a dangerous and delicate operation. It has now been lined throughout with brickwork in cement. After leaving this tunnel the line again passes under one of the perpendicular cliffs, which it has been necessary to cut back. All this cliff cutting and the tunnel, and some length of line, might have been avoided if the line had been taken across the river and back again in a straight line. It would have given a shorter, better, and safer line, but the enormous cost of the two bridges deterred the engineers, although I think it is very likely that eventually these bridges will have to be made.

The first of the present bridges across the Nari is at a place called Tanduri, six and a half miles from Nari (*vide Plate* IX.). Tanduri means an oven, and the name is singularly appropriate, for the heat there in summer is terrific. This bridge was originally of five spans, since increased to six spans, each of 150 feet. This work was begun by Captain Davidson, R.E., in January, 1884, and finished in March, 1885. It has presented no great difficulty; the piers are not very high nor the foundation rock very deep. A good sandstone quarry near the site supplied stone for piers and abutments, and the general position is sufficiently open to make all the accessories for the work easily laid out and arranged. There is a small rectangular fort near at hand, in which are quarters for the men employed on the work, and stores of all kinds for use on the bridges are kept.

After this the gorge widens a little, and the line crosses an open plain for a mile or two, and plunging through a rocky spur of the hills at Kelat-i-Kila, again meets the river, and crosses it on a bridge of four spans of 150 feet and one of 40 feet. The site of this bridge is narrow and awkward; the average height of the piers is 45 feet; they were built of stone from a quarry some two and a half miles off. Great difficulty was experienced in securing these foundations, owing to repeated floods, but Lieutenant Thackwell, R.E., who was in charge, was very successful in overcoming all difficulties. The work was begun in December, 1884, and the last girders were rivetted up in June, 1885, so no time was lost, in spite of the disastrous floods in January, March, and April.

In the next three miles there are no fewer than four bridges, (*vide Plate* IV., *Figs.* 1 and 2, also *Plate* V., *Fig.* 1), all of the same character, each with five spans, generally of 150 feet, and with piers of about 28 feet average height. The foundations of some of these piers gave much trouble; and in the absence of anything like good building stone (which was not procurable), or of fuel to burn bricks, the piers and abutments were all built of Portland cement concrete in blocks, which will be hereafter more fully described. These four bridges were for the most part entirely built in the winter of 1884–85, but four of the most troublesome of the river pier foundations were secured during the early months of 1884. The girders had not been erected on any of these bridges in June, 1885, but all the masonry was quite ready to receive them. Near the last of these four bridges is the meeting-place of all the waters alluded to above. Much difficulty was experienced in keeping the line and banks free from the destroying action of the waves. At the extreme end of the gorge there stands the great Babarkach rock, round which in time of flood the waves whirl and roar with much fury. The line passes through this rock in a tunnel some 250 feet long. It was proposed at one time to blow up the whole mass of rock, which is made of hard conglomerate. Mining galleries were laid out and driven by the sappers of the 7th and 10th Companies Bengal Sappers and Miners. The charge required was about 60 tons of gunpowder. The idea, however, of this great blast was abandoned in favour of a tunnel, because some preliminary mines that were fired gave unsatisfactory results.

The second difficult portion of the line is the Kochali defile, some three miles beyond Babarkach. Here for five miles we have a narrow and winding ravine, through which, in time of flood, a river comes with sudden and great violence, passing between steep hills that rise almost vertically on both sides. The longitudinal slope of the ravine is greater than the maximum gradient of the line, and so the line has to enter the lower end at a considerable height. The soil is clay shale of a very treacherous nature. The cuttings on this part are perhaps the most troublesome on the whole line, some of them being as much as 100 feet in depth. Heavy revetment walls have been required to support the slopes of the embankments, as the width of the defile does not admit in most cases of the slope reaching the ground in the ordinary way. There are three very heavy bridges, each of an average length of 300 feet. The first of these rises to a considerable height, the piers being 67 feet high (*vide Plate* III.). Between the first two bridges is a tunnel 540 feet long, passing through a neck in the hills. The heading of this tunnel was made in the early months of 1884 by the 5th Company of Bengal Sappers, under Lieutenant King, R.E. It was taken out to full width and lined with brickwork during the cold weather of 1884–85. The danger in this work from the falling of earth and shale was very great, and many lives were lost. There is another small tunnel towards the upper end of the defile, but it is only 120 feet long. It was begun and completed last winter (1884–85), under Lieutenant Capper.

From Kochali to the Chappar rift there is no great difficulty to be encountered. There are two heavy bridges at Zindagi-Ab, between Kochali and Spintangi; there is another over the Garmai river at Spintangi, and three between Spintangi and Harnai. There is one tunnel through white marble rock at Spintangi. But there is no exceptional difficulty about any works until the Chappar rift is reached, and this is the *crux* of the whole line from Sibi to Peshin.

The Chappar rift is an extraordinary freak of nature (*vide Plate* VI., *Fig.* 2; *Plate* VII., *Figs.* 1 and 2, etc.). Imagine, if possible, a mountain range broken asunder at right angles to its contours. Down the chasm thus formed, a mountain torrent forces its way through enormous boulders, the quantity of water in summer being a mere trickle, but in time of rain a boiling torrent completely filling up the rift from wall to wall and effectually preventing anything from passing up and down. The main caravan route from Kandahar to Sibi *viâ* Harnai led through this rift, and in 1880 the roadway was improved and made passable for artillery. But every flood destroyed this road, and recently a road has been made over the top of the mountain; the existence of this upper road was rendered necessary on account of the quantity of débris which was then being shot over the edge to the bottom of the rift by the railway tunnel and cutting works. The longitudinal slope of the rift is about 1 in 20. The maximum gradient of the railway is 1 in 45. Hence, to effect an exit at the upper end it is evident that the entrance at the lower end must be at a very high level. To gain this height was one of the engineering problems that presented itself. It was managed as follows:—The stream through the rift joins at its lower end a valley at right angles to the rift reaching towards Khost. The railway coming up from Khost was kept on the side of that valley opposite to the mouth of the rift, and continued up and past the mouth until it had met naturally the stream coming down, then it described a complete semi-circle, and, crossing the stream, skirted along the face of the rock towards the rift. The next question was how best to take it along the face of the rock. An embankment on the face of a rock with a cross slope of 1 in 2 was out of the question, for the lower end of the bank would be in the air. A cutting was objectionable because of the violent storms of rain which occasionally fall. The water pouring off the rock above into the cutting would turn it into a water-course. It was suggested to drive iron standards into the rock and lay girders on them. This would allow the rain water from above to pass below the line, but if a train got derailed it would have nothing to save it from utter destruction. It was finally decided, therefore, to make what in Persia and Afghanistan is known as a "karez," *i.e.*, a tunnel passing just under the surface and connected by many shafts. These karezes are made largely by the natives to bring water from springs at the hills to irrigate their fields. By adopting this principle to the railway, the surface water would readily get away over the line, and yet the train would be quite safe in case of accidents.

This covered passage, or "karez," is divided into two parts, the first having eight shafts and a length of 817 feet, the second 12 shafts and a length of 1400 feet.

After passing through these karezes it has been found necessary to tunnel through a jutting portion of the mountain. This tunnel is 645 feet long; it was a very troublesome heading to drive, owing to difficulty of access to it.

The line then reaches the edge of the rift, and has to leap across to the opposite rocky wall of the chasm. The bridge which takes the line across is 200 feet above the bed of the torrent below; it will consist of two spans of 150 feet, and some two or three spans of 40 feet. The line then immediately plunges again into a tunnel 542 feet, curving round to the left. Emerging from this, it enters the core or heart of the rift, where the chasm widens out to an oval shape, a high wall of rocks all round the edges, and the sides formed of débris of rocks and shale. The railway winds up the eastern side of this, in cutting and bank alternately, until it has to penetrate the rock afresh at the place where the rift again narrows in. This tunnel (No. 3) is 1251 feet long, but it has presented in some respects less difficulty than some of the others, as it has been possible to have no fewer than seven adits leading into it from the face of the rift (*vide Plates* VII. and VIII., *Fig.* 1). There is beyond it a somewhat heavy rock cutting, and then the line finally plunges through the last of the rift tunnels 437 feet long, and emerges into the upper valley at Mangi (*vide Plate* VI., *Fig.* 2).

The tunnels aggregate a mile altogether.

Taken as a whole the work on the Chappar rift is a very bold piece of engineering. It was planned by Brigadier-General Browne, working in constant consultation with Captain B. Scott, R.E., who has continued in charge of the works as executive engineer since their first commencement. The starting of the work was a matter of no small difficulty. A very careful survey of this most precipitous ground had first to be made, then the levels had to be fixed and the line located, then work had to be begun, all of which operations were not only difficult, but extremely dangerous, involving a very steady head and good nerves. When the position of the line had been fixed, men had to be lowered from the summit of the crags on cradles or platforms, and from this position had to make foot-holds for themselves on the smooth vertical face of the cliffs. Nor was this all. Violent floods so frequently prevented all ingress and egress to the rift, that Captain Scott saw it was necessary to make a high level road that should be independent of all floods. This was done by taking advantage of ledges and shelves of rocks; and where no such ledges existed, iron bars were driven horizontally into the vertical rock face, and supported a roadway of planks or chesses (*vide Plate* VII., *Fig.* 1). This upper road enabled the working parties to come and go independently of the weather. Of course this high level road is merely for foot passengers. For all animals, and for the regular heavy traffic of the country, a road has been made, as I have already mentioned, over the top of the mountain.

So carefully and well was the work on the Chappar rift organised, that in spite of bitter cold it went on steadily all last winter (1884–85), although occasionally there were difficulties of supplies, both of food and stores. The work was then placed in the immediate charge of Mr. Rose, a civil engineer, working under Captain Scott's direction. It is hoped that the tunnels will all be completed in December, 1885. They were begun in June, 1884.

Much credit is due, let me here state, to the men of the Bengal Sappers and Miners, especially the 5th, 9th, and 10th companies, for the way they began these works, especially in the construction of the high level road, and in beginning the adits. These men worked fearlessly and well in positions of much danger, and they accepted the difficulties of the work in a proper soldier-like spirit as a compliment to their skill and aptitude.

We have so far glanced at three out of the four difficult portions of the line. The fourth is the "summit" section, which may be said to extend from Mud gorge to Garkhai, a distance of about 18 miles. Mr. Molesworth, indeed, considered Mud Gorge (a place half-way between the Chappar rift and Kach) a more serious engineering difficulty than even the Chappar rift. It is a wild and precipitous glen, about three miles long, with a longitudinal slope at first of about 1 in 30, gradually lessening to 1 in 70. The soil is extremely soft and treacherous; it has the appearance of loose mud—whence the name of the place—and at first it seemed necessary to make two large tunnels and some four or five high level bridges. However an alteration in the alignment got rid of all these works, and a huge cutting 75 feet deep and 1200 feet long is now the most formidable operation to be undertaken, and it is possible that some revetting or lining will be required protect the sides of this cutting. There is also a short bank 105 feet high. But even these heavy works are far better than the tunnels and bridges for which they they have been substituted.

Much care and attention was bestowed on the selection of the alignment on this "summit portion." The country through which the line here passes is very broken and mountainous, and on the old plans there appear some terribly heavy works, such as a 60 feet bank for nearly a mile, a bridge 120 feet high, etc. Careful survey eliminated all these difficulties. Under Captain Hoskyns and Lieuts. C. Cowie and Petrie, an entirely new line was selected, which might, I think, be taken as a model for the adapting of a line to the contours of a country. In one place there is a "corkscrew," or spiral, a device which is common enough on such mountain lines as the St Gothard, but unknown either in this country or in India. The line takes a complete turn under itself. The whole alignment on this section was laid out with such care and such a light line, comparatively speaking, selected, that the whole of the earthwork was completed in five months. This rapid work was the result of Capt. Hoskyns' organisation, and when he went away to active service in the Zhob Valley Expedition, the work was well sustained by Lieut. Thackwell, who was placed in temporary charge.

From Garkhai to Quetta there are no engineering difficulties. The country is quite open, and the line lies along the surface. There is one tunnel through hard lime-stone rock, and a bridge of four spans of 40 feet over the Quetta Lora river. At Bostan there is the junction of the main line from Sibi to Peshin, and the branch to Quetta. Bostan is a little village surrounded by fields on the left bank of the stream called the Kakar Lora. It will doubtless be a place of some importance, not only as a railway junction on the Peshin plateau, but because it is proposed to put workshops, locomotive sheds, and staff quarters there. It is proposed to fortify the site and to protect the adjacent bridge also by a *tête du pont.* The climate is temperate, and the garrison there will not be badly off.

After leaving Bostan the line passes through a low range of hills, and five miles from Bostan reaches the new cantonment of Peshin. The destination of the line after this is uncertain. It may cross the Peshin plain to Kila Abdulla, and tunnel through the Khojak range to Chaman. This would have the advantage of giving a direct route, but one attended with extraordinary difficulties. Three miles of viaducts and a tunnel two miles, perhaps four miles, long would be necessary, and as the soil is indurated clay, like the Kochali tunnel, this would add to the difficulty of the undertaking, as it would have to be lined throughout. There would be great delay and difficulty in starting a tunnel at such a distance from the base.

Again, even if the line did reach Chaman, it could not go direct to Kandahar. There are some 15 miles of slope below Chaman, and the line would have to zigzag down this glacis, and then travel westward to a point to the south of Kandahar.

An alternative scheme for the extension of the line is to take it along the Quetta branch as far as the Quetta Lora bridge, and then, instead of striking south-east to Quetta, take it almost due south towards Nushki, which is quite clear of the Gwaja Amran range. It may be remembered that the Afghan Boundary Commission last year went *viâ* Nushki. Taking the comparative lengths of the two lines *viâ* Chaman and *viâ* Nushki, it appears that, measured from Bostan, the latter route is the longer, but it would cost less than the Kila Abdulla line, and could be started at once. Strategically it would be a better line, as it would run parallel to the frontier, and in rear of the important military position on the Gwaja Amran range. Another line could, moreover, be taken from Nushkito Kawaja Sultan, on the banks of the Helmund, whence the communications between Herat and Kandahar would be threatened. The Nushki line would not only be cheaper, but could be finished more quickly than the other. Nearly the whole length is surface railway; there is but one tunnel, 300 feet long, and 600 feet of bridging. The ruling gradient is 1 in 100, as against 1 in 45 on the other line. Thus the Nushki line would be completed in half the time, and carry about double the traffic. The only objection to the Nushki line is that it passes through a portion of the Amir's territory, between the Ragistan Desert and the Amran range.

At Bostan, however, the first great stage on the road is reached. The great watershed between the Indus and Afghanistan has been crossed. With the railway thus in the great upland plain of Afghanistan, we can wait further development of events.

The line will probably be open for through traffic to Peshin by the end of the financial year 1886–87, *i.e.*, three and a half years from the commencement of the works in October, 1883; and had it not been for the exceptional floods and sickness that have so fatally hindered the work hitherto, probably this estimate of time would have been reduced by at least six months. It is most annoying to reflect that the years 1881–83, when the works were stopped, were years of exceptionally good weather, and of very healthy seasons.

There is another very important line, the temporary Bolan line, of which a brief description may be interesting.

I have already pointed out that the reason the Harnai route was chosen instead of the Bolan as the place for a permanent line, was that on the Bolan it was not possible to get a grade of 1 in 45, whereas it is possible to do this on the Harnai route. On the other hand, a glance at the map will show that the Bolan route is by far the shorter to Quetta and Peshin. A military road was constructed up the Bolan Pass in 1882–83–84 as far as Quetta, with a ruling gradient of 1 in 20. This road was a work of very considerable difficulty, but it was admirably made, and will always be of the greatest value as a military communication. In July, 1884, the question was raised by the Government of India whether it would be possible to supplement the work of the Sind Peshin Railway by constructing a line for part of the way up the Bolan. It was then well known that the railway by Harnai would take some time to construct, and as difficulties with Russia appeared threatening, it would be as well to know how far existing communications might be utilised or added to. It was thought that rails might be laid on the already existing military road up the Bolan. This matter was referred to the Superintending Engineer at Quetta, with the reply that a railway might be made up the Bolan in continuation of that already existing, as far as Mach, half-way up the Pass, and forty miles from Quetta; that for eighteen miles beyond Mach the steepness of the gradient would prevent a railway being made, the gradient there being 1 in 20; that for the last twenty-two miles into Quetta it would again be possible to construct a line on the 1 in 45 grade, and at Quetta a line so constructed would join the Bostan Quetta branch of the Sind Peshin Railway.

In March, 1885, it appeared as if war with Russia was absolutely certain. Orders were given to the Commissariat and Transport and other departments to collect vast quantities of warlike stores at Quetta, and very extensive arrangements were made for establishing a transport train of carts, camels, and other pack animals, from Rindli, the terminus at the mouth of the Bolan, to Quetta. The station at Rindli was at once enlarged, new sidings were put in, and very complete arrangements begun for the increased traffic. The amount of material of all kinds that kept pouring in along the Sind Peshin Railway was enormous. A glance at the map will show how difficult it was for the single line across the desert to bear the strain of traffic pouring in from two directions. From the Punjab by Multan and Sukkur, and from Bombay *via* Karachi and Sind, trains of stores and troops came daily for the front to Ruk, and these had to be despatched along the single line from Ruk to Rindli. In fact, this single line was called upon to do the work of a double line. That it was able at all to cope with this double burden of military traffic, without delay or accident, and yet send on ordinary stores as well, was greatly to the credit of the manager, an officer of our Corps. I have mentioned this because I saw lately a paragraph in a newspaper making calumnious and sweeping assertions against the corps in general, and this officer in particular, with regard to their efficiency as railway managers.

At the beginning of April it was resolved by Government to extend the line up the Bolan somewhat in the manner proposed the previous summer, in order to ease the difficulties of transport; for, of course, the railway brought five or six times as much in the way of stores as the transport train and camels could carry away. This railway up the Bolan was to be entirely a temporary arrangement. It was not laid on the military road, as at first proposed. The reasons for this, doubtless, were that the road required all its width for ordinary purposes, and that no reduction of that width could be afforded. Also, that it would never do to obstruct the traffic with railway working parties. Further, the road lies above the highest possible flood level, and hence at all the road bridges, railway bridges also above flood level would be required, and the construction of these would take a great deal of time, and defeat the aim of the whole work, a quick temporary line. So the rails were simply to be laid in the bed of the river, which is wide and straggling, and has at most seasons but little water in it. Heavy floods would, of course, knock it to pieces, but these are not, as a rule, of common occurrence, and the line might take its chance of them. Where it has been necessary to cross the river, low crib bridges have been made, *i.e.*, cribs of sleepers weighed with boulders, and protected as much as possible by stone pitching. At these crossings the line has been laid as low as possible, so as to present as little surface as may be to the action of a flood. Of course, during a rainy season it might be impossible for an engine to get over one of these crossings for a week or a fortnight, even supposing the pier foundations remained sound. Still, one must accept a certain amount of risk in all works constructed in war, and a state of war or extreme danger would, in the opinion of those best qualified to judge, alone justify the construction of such a line.

Colonel Lindsay, R.E., was at first nominated to be Engineer-in-Chief of this line, and he started the work in April, and continued in charge till the end of May, when he met with a serious accident which obliged him to go to England. He was succeeded by Mr. O'Callaghan, a civil engineer of great skill and experience, by whom the great bridge at Attock was built. Under him was a large staff of engineers, chiefly civilians. There were among them two captains in the Corps, and the only reason that there were not more is that the Government of India had, up to a recent date, given few facilities to officers of the Corps for entering the railway branch of the Public Works Department, and hence there are not many officers of the Corps in that branch under the rank of Major. Nearly every one of these was engaged on the Sind Peshin line already, so there were no more for the Bolan.

The work on this line, constructed on the temporary principle indicated above, was carried on during the whole of the summer months, and was completed as far as Mach by the 1st of November, 1885. It is impossible to describe adequately the difficulties and privations under which this work, like the other, was carried on. Cholera and other fatal diseases carried off thousands, sparing neither high nor low, European or native. The heat in the lower Bolan, too, is beyond all description; and, hence, though the engineering was not of the same character on this line as it was on the other route, the initial difficulties were much the same, with one notable exception, that the presence of the first-rate Bolan road facilitated work there in a way that on the other pass was unknown.

Beyond Mach it was at one time proposed to haul trucks up the incline to Darwaza by means of stationary engines and wire ropes, but this idea has been abandoned. I understand that it is now proposed to lay a temporary narrow-gauge line (3 feet 3 inch gauge), with special rolling stock (Fairley engines and bogie trucks). One difficulty will be the supply of water, which in the upper Bolan is very deficient. I hear, however, that arrangements are being made to raise water from springs at Dozan (half-way up) by means of pumps, a height of 350 feet. A supply of iron pipes is being obtained from Suakim, where they are no longer required.

It is expected that the line will be open to the summit of the pass by the 1st of January, and into Quetta by the 1st April, 1886, probably a year before it will be possible to arrive there by the other route.

The Bolan temporary line undoubtedly hindered the progress of the work on the Sind Peshin State Railway by taking away numbers of the workpeople, who had got disheartened at the heavy difficulties and repeated floods, and who, moreover, always will leave an old work for a new one. But it will, it is hoped, help the Sind Peshin State Railway in the future by bringing up material for the Quetta branch, and further.

Some writers in the Press, jealous of the Corps of Royal Engineers, have made invidious comparisons between the progress of the Bolan railway, on which the engineers are chiefly civilians, and the Harnai line, on which the Corps has been so largely represented. But no engineer in his senses would think for a moment of comparing the two. There is no comparison between a permanent line, independent of floods, and a temporary line laid in the bed of a river.

We have, on the contrary, while giving our civilian brethren every credit for the work in the Bolan, good reason to be proud of the work done by the Corps on the Sibi Peshin line. It has been entirely under the direction of one of the most distinguished officers of the Corps, of whom I think I may be permitted to say that there are few men who, in the face of such difficulties as we have had, could have carried on such an undertaking with so much success, and all the difficult works on the line, without exception, have been either partly or altogether under Royal Engineer officers. From

Nari to Nasik, from Dargi to Quetta, there is no part that has not been under Royal Engineer executive engineers, and the only part that has been under civilian engineers is the easiest part of all, the only part, too, that enjoys a fairly temperate climate.

A subsequent lecture will deal with details of construction.

LECTURE III.

Our attention has hitherto been directed to a description of the frontier railways in general, and to the Sind Peshin State Railway in particular. Let me in this lecture ask your attention to some details of engineering construction in the latter line.

I must preface my remarks, however, by saying that probably many of the points to which I call attention, and many of the engineering details which I describe, are not by any means new. There are certain matters of engineering which are common to all railways, and for the matter of that to all large works; and these common points I shall endeavour to avoid. The details I am about to describe are those that were new to me personally, and to almost every officer in our Corps who joined the line while I was there. Many of us had had experience in the construction of barracks and forts, in the laying out of military roads and building of road bridges; some of us knew a little about canal engineering, which is even more precise and exact than railway work, but with two or three exceptions, the Royal Engineer officers sent up to the works knew nothing, practically, about the technicalities of railway engineering; did not know how to lay out curves or to set out bridges; did not know how to set out tunnels, and were quite ignorant on the subject of platelaying, and the peculiar circumstances of the country were so many, that even those officers who had had a great deal of railway experience found still that there was much to learn. This applies not only to our own people, but also to the civilian engineers. Many of them were gentlemen of large railway experience, but they found that they had a great deal to pick up on this peculiar line.

I shall, therefore, be glad if by relating our experience I can give some of my hearers an idea of how to set about their work, if they should have similar work to do. I shall try and point out the practical lessons which I, in common with others, learnt on this great work. It is better to have some idea, even if it only be in theory, of the work to be done, and not to have to learn it at the cost of disagreeable and humiliating failure as well as of valuable time.

The first point in the construction of a line is the survey, location, and staking out. The general direction of the line, the points it is to pass, the stations, etc., are fixed by superior authority, and general instructions on this ground would be issued as a matter of course. As regards the special location of the line, technical orders of a precise nature would be issued by the Engineer-in-Chief, who in every case goes over the ground with the executive officers and issues orders to them as to the route, or the various alternative routes, he wishes to be laid out and levelled. The actual staking out, traversing, plotting, and levelling, almost invariably fall to the lot of a junior officer to carry out. The laying out of a line is in most cases simply a question of trial and error. Sometimes one can see at once the best place for a line to pass, but very often it is difficult to tell which of two or more alternative lines is the best, until they have been surveyed, marked out, and plotted on paper. As this is generally the first duty an officer has to do, it is very important for him to be thoroughly conversant with the laying out of curves and in taking levels.

As regards both these points, curves and levels, let me merely say that the American methods are far superior to the English. The English method of carrying out a curve is arbitrarily to fix a radius, or an apex angle, and to calculate therefrom the tangential angle by means of a regular formula. This involves a long arithmetical calculation, which carried on under most uncomfortable conditions, as it generally is, is almost certain to be wrong. It is pitiable to sit down on a rock, under a blazing sun or pelting rain, with a book of logarithms, to work out an angle which generally comes out in minutes, seconds, and fractions of a second, and which therefore has a further liability to error in the number of times it may have to be repeated round the curve. The American method is far simpler. In it the tangential angle is arbitrarily fixed, not the radius. All that one wants is a table of radii corresponding to even tangential angles, and from these one can select what would give a suitable curve, and then proceed to lay out the curve with accuracy and speed, and above all without loss of temper. I have not time to go into full details on this subject; it can be learnt from a small book entitled "A Practical Treatise on Railway Curves," by a Mr. Shunk, an American engineer.

The American method of levelling has a great advantage over our method, in that it is simpler, the books can be kept more neatly and checked more readily. The rule is a very simple one. To the reduced level of the starting point add the level of the backsight; this gives the level of the axis of the instrument. From this level all foresights are subtracted, whence the reduced levels of all the foresight positions are at once obtained.

Once a line has been determined upon and staked out, the next work is to lay out cuttings and embankments. It is generally advisable to calculate the cubic content of any piece of work before it is given out to one of the numerous petty contractors; who are always to be found on such works. With regard to cuttings; the practice on our line generally was to mark out the exact formation width at first and let the sides be cut vertically, then afterwards to lay out the slopes, which were generally, though not always, $\frac{4}{1}$. In gravelly soil, curiously enough, it was found that the rain had less destructive effect upon vertical sides than upon $\frac{4}{1}$ slopes. As regards embankments, the formation levels and the edges on both sides should be marked out, and if possible profiles put up at regular intervals.

It is always customary to mark every tenth peg on the line with a small masonry pillar, and also to build a small pillar round the tangent peg of each curve.

The laying out of bridges is a matter requiring the greatest care and accuracy, and it is often a matter of no little difficulty, owing to the nature of the ground. This duty almost invariably falls to an assistant engineer, and it is well worth while to take pains and ensure accuracy at first, for a mistake in measurement, which perhaps will not be discovered till the girders have to be erected, may cause the whole work to be at fault, and render the labour of months useless.

The first thing to be done is to determine accurately the centre line of the bridge longitudinally. If the bridge is on the straight, which it generally is, the way to do this is to set up the theodolite on the tangent point of the nearest curve on one bank, and direct it on a pole or flag erected on the tangent point of the first curve on the opposite bank. This gives the vertical plane of the centre line. Mark out with pegs, in any convenient number, the centre line thus obtained, accurately across the bridge site; especially have some, if possible, in the bed of the stream. These pegs may be built round with masonry. The site of one abutment will probably be fixed by superior authority, and the position of the centre line on the face of this abutment must be marked. From this mark the measurement for the spans and piers must be taken. It should be remembered that when girders of a given span are to be used, this means the span in the clear, not the total length of the girder, and hence, in laying out a bridge the distance between the piers must be the given span plus the width of the pier. Thus, for instance, in a bridge of three spans of 150 feet, with piers 12 feet thick, the centre lines of the two piers would be 162 feet from each other, and 156 feet from the face of each adjacent abutment.

To measure these distances accurately, it is generally advisable to take a base in any convenient direction (one parallel to the centre line of the bridge is often most convenient), and measure the distances there with measuring rods, and with a steel tape, then fix the centre points of the piers by triangulation. Of course, if the site will admit of measuring the distance on the centre line of the bridge itself, so much the better, but it is always well to have an outside base as a check. The centre points of each pier being obtained, their centre lines are then laid out at right angles to the centre line of the bridge, or if the bridge is skewed, at the angle of the skew. The centre lines of each pier, and the faces of abutments, should have their positions fixed by pegs or masonry pillars, built at points up and down stream on sites above flood level, so that if a flood comes and destroys all the work, the line may be taken up again at once.

Having got these preliminaries settled, and the centre lines in both directions accurately fixed, the next thing to be done is to excavate the river bed for the foundations of the piers. This is generally a very difficult task. Some of the pier sites are certain to come in the water, and to get at these sites the first thing to be done is to divert the stream and build clay embankments round the site, high enough to resist a small flood. Of course, if a big flood comes, there is nothing to be done but try and save plant and tools, it is impossible to provide against every contingency. But the banks or dams ought to be high enough to resist a small flood. The site being cleared, the excavation through the sand and shingle of the river bed is begun. It is tedious troublesome work, and it will be found that progress is much hampered by water percolating through from the main stream. The deeper the excavation, of course the greater this percolation. This water must be kept out altogether, and to this end pumps generally have to be employed. Sometimes the water can be baled out by hand, sometimes the quantity is only moderate, and such as can be kept down by hand pumps. Very often, however, hand pumps are found insufficient, and then steam power has to be resorted to. Of course the expense and trouble of steam pumps is so great that they should not be used if manual labour can be utilised and is sufficient. At the same time the foundations must be absolutely dry, and no expense must be spared to ensure this.

A very convenient sort of pump in these situations is the pulsometer, the great advantage of which is that it does not require a portable engine with its staging and belting. The boiler to work the pulsometers is easily moved; it can be erected at a safe distance from the work, and one boiler will generally work two or three pumps.

These pumps, too, can be used in situations where it is not practicable or easy to use any other sort of pump—they can be lowered into a well, for instance.

If, however, the flow of water into the foundations is very great, pulsometers may not be strong enough, and then the only sort of pump to use is a centrifugal. This discharges a far greater volume of water than any other kind. The only objection is that it is rather troublesome to manage, a portable engine is necessary, with belting, and the bank adjacent whereon this engine stands has, of course, to be made very secure. The pump itself has to be on very strong staging over the water, otherwise the pull of the belting will overturn it. Then arrangement has to be made for the due disposal of the discharge water. Centrifugal pumps certainly have the great advantage of power, and for this reason are very largely employed in open foundations. It is unnecessary for me here, and it would be out of place, to enter into a detailed description of these pumps, as they can be seen on works in England. I would merely say that a thorough knowledge of the details and practical working of pumps is of great value to the railway engineer.

When the shingle of the river bed has all been taken out and the rock reached, the latter must be made ready for the reception of the concrete in the foundations. No time must now be lost, and every available man must be put on the works. Arrangements should be made for lighting the works, and for regular night reliefs, so that the work may go on day and night without interruption. A flood at this juncture will upset the labour of weeks. For instance, at the Kelat-i-Kila bridge the foundations of two piers were swamped by floods twice, thus the work had to be done three times, and, of course, all the plant on the work, engines, boilers, pumps, etc., were completely ruined, where, indeed, they were not entirely lost.

The rock bed must be roughly levelled for the concrete. If there is a natural slope, stone-cutters must be set to work to cut it into steps with dovetail joggles, to give the concrete a firm hold. If it is naturally level, it is sufficient to clean the face and smooth off inequalities. Any honeycombing which may have taken place by the action of floods must be carefully removed until solid hard rock is reached. A low wall of boulders in mortar is built round the outside of the foundation site, and the concrete is then laid. The Engineer-in-Chief liked always to inspect the site before the concrete was put in, so that he might satisfy himself as to the thorough soundness of the rock-bed on which the pier was to be built. The Portland cement concrete was commonly used in the following proportions :—one part cement, three parts sand, eight parts shingle or broken stone. For portions of the pier where the exposure was greater or more strength required, the proportion of cement was higher. The superstructure was always, where possible, built of ashlar masonry, with courses not less than 10 inches thick. But quarries were not always to be found ; indeed, in the great majority of cases there was no building material near at hand, except the sand and shingle in the river beds. So it was decided to build the piers of concrete blocks of similar proportions to the concrete used in the foundations. The moulds for these blocks were 2 feet × $1\frac{1}{2}$ feet × 1 foot, and were simply wooden boards with wedge keys. The moulds were placed on the sandy ground near the work, and the concrete was then rammed into them and left for three or four days. The date was written on each, and after four days the concrete had attained sufficient hardness to admit of the boards being knocked away, and the block being carried to the work and laid in position. The blocks were laid like bricks, breaking joint and preserving a bond, all round the outside edges of the piers, and the inside of each layer was filled up with loose concrete. Thus the entire piers were built of concrete, rapidly and firmly. The concrete bridges near Babarkach (*vide Plate* IV.) had a very severe test in the floods of April, which occurred just after they had been completed. The result however was most satisfactory, no part of any pier showed signs of disintegration.

I may mention, that in mixing the concrete the Engineer-in-Chief directed that the sand and cement should first be measured and mixed dry, and then mixed with the measured shingle, also dry. During this second mixing water was sprinkled in very moderate quantity.

To raise the concrete blocks, and the large and heavy stones for the ashlar work, to their required positions on the works, one method, which seemed to be a favourite plan with native workmen, was to use inclined planes built of rails, and planks lashed across the rails. But a more scientific and satisfactory plan was to erect light derrick cranes at each pier. These cranes lifted weights up to about two tons, and were arranged so as to work in a horizontal and a vertical plane. The jibs were about 20 feet high, so the operations of the crane were limited to a hemisphere of 20 feet radius, with centre at the foot of the jib. To enable them to be used with piers of 40 feet or 50 feet, the cranes were erected on sandbag platforms of sufficient height to enable the top of the jib to reach well above the highest point of the pier. Another method for lifting stones, etc., was to erect a sheers to reach above and over the pier, and have blocks and tackle with the running end of the fall round a windlass at the bottom of the pier, where there was plenty of room to work it with handspikes. But none of these ordinary methods were sufficient for raising the large stones required for the girder bed plates. At first these stones were obtained at enormous expense from quarries in the Northern Punjab. Each was 7 feet long, 5 feet wide, and 2 feet thick, the total weight being 3 tons, more or less. They were transported to the site of the work with much difficulty, then holes had to be bored through them for the anchor bolts, and then special lifting arrangements had to be made before they could be raised into position. The expense and difficulty of all this proved to be so great that it was decided to make the bed plate blocks of Portland cement pure, or mixed with sand or fine shingle in small proportions. By this method the anchor bolts could be put in position before the cement was put in, there would be no trouble in raising the cement, and the whole mass would be thoroughly hard and homogeneous. It would have plenty of time to set before the weight of the girders was brought on it.

The girders are all made and designed in England. The only work to be done in India is to put them up and rivet them together. With small girders up to 40 feet span, the invariable method was to rivet up the whole first, and lift it bodily into position by means of a single pole derrick (*vide Plate* III.). With large girders two single pole derricks were sometimes used, one at each end of the span, both ends being lifted together. In this case also the entire girder would be rivetted up before lifting. The most common method, however, for large girders was to build them up on staging. The staging used by Mr. Sullivan, the contractor, consisted of short lengths of wrought iron pipes, fitted into sockets at each end, and tied together by iron bars; a very neat and portable, and yet very strong, arrangement (*vide Plates* III., IV., etc.). These groups of staging were founded on iron girders resting in the river bed, and were connected above with iron girders, on which were rails for a Wellington crane or traveller. This traveller worked longitudinally along the whole span, and transversely for its own length, viz., about 20 feet, so that it could lift into its required position any part of the whole girder. The time generally taken by this method to build up a 150-feet girder was 18 days. The chief objection to this method is that a flood during the work will carry away the staging (*vide Plate* VIII., *Fig.* 2). Another objection is that with a Wellington crane native workmen have to be very carefully watched. With the usual carelessness of Asiatics, they will, if allowed to do so, work the crane without preventer blocks or chains. On one occasion the whole crane tumbled over a pier into the next span, killing two men and wounding five. On the whole, however, this method of erecting girders is very rapid and efficient.

Before finally leaving the subject of girder erection, let me state that the knowledge of the manipulation of heavy weights in such artillery exercises as are taught at Woolwich and Shoeburyness, with the accompanying instruction in the use of ropes, chains, blocks, and tackle, is of the greatest value to the railway engineer, and I would strongly recommend to all who have the opportunity, and who wish to become efficient as railway engineers, to study by all means in their power this branch of practical mechanics, and the use of these appliances.

To turn to another subject of much importance in railway engineering—tunnels. Those on the Sind Peshin line, as indeed on all lines, are of two sorts, viz., lined tunnels through soft soil, and unlined tunnels through rock. All the Chappar rift tunnels, the Spintangi and the Quetta tunnels, are through rock quite solid enough to stand by itself. The other tunnels on the railway are lined. Lined tunnels are more dangerous in construction than tunnels through rock, though the latter take longer to construct, and require a greater expenditure of explosives. As regards the question where a cutting should end and give way to a tunnel, of course the reply varies very much with peculiar circumstances, but I think that, as far as possible, 80 feet was about the maximum depth that a cutting could be conveniently taken to. Anything beyond that should be a tunnel. The first tunnel on the Sind Peshin line, at Nari gorge, was, as I have stated in a previous lecture, driven through soft sandstone rock in 1880, but not lined till the beginning of 1884. It gave then the greatest trouble and caused enormous expense, chiefly because it was not lined at first. It is most dangerous to take a tunnel out to full width in soft soil, and allow, as in this particular case, trains to run through it. The vibration of passing trains may loosen large portions of soil, and cause the most serious accidents. In making a tunnel through soft or treacherous soil, the first thing to be done is to drive a heading through, about eight feet square, with sides and roof well shored with timber. This heading should be situated so as to be nearer the top than the bottom of the tunnel, as it will eventually be, because in widening it is easier to work it when the heading is well above the floor.* When the tunnel is enlarged to full size, small portions, about six feet in length, are done at one time, so as to lessen risk of landslips. With a single line of rails the cross section of the tunnel would naturally be somewhat oval, and the centreing used conforms to this oval shape. Moveable wooden centreings are usually employed, running on wheels with the widest possible track, and with sufficient space underneath to allow trucks to run between the wheels. The lining was generally of brick laid in Portland cement, and the space between the extrados of the arch and the ground above was filled up with coarse rubble masonry. Sometimes voussoir shaped concrete blocks, made in similar fashion to the blocks used on the bridges, and already described, were used for tunnel linings where brick was not forthcoming in sufficient quantities. As regards the direction of tunnels, in most cases it was possible to run a traverse from one mouth of the tunnel to the other. By reducing the triangulation thus obtained, and allowing for the curvature, if the tunnel was on a curve, it was generally possible to fix exactly the position and direction from both ends. But in some cases the nature of the ground was so difficult, and the mouths of the tunnels so inaccessible, that the only thing to be done was to make a very careful trigonometrical survey, and plot the work on a large scale plan, from which the lengths and directions could be taken off by scale. This was the method followed at the Chappar rift, and on the whole it was quite successful. In these tunnels at the rift it was a matter of much importance to have as many shafts, adits, or auxiliary galleries leading into the tunnels as possible, so as to be able

* This would only apply to tunnels where water is not expected to be met with, as would probably be the case in India. If difficulties with water are anticipated, the heading should be at the bottom of the excavation, as when opened out it drains the whole of the workings.—[Ed.]

to employ more and more hands at once. When a tunnel passed under a very high rock, or at some distance horizontally from the face of a cliff, it was not possible to use any auxiliary shafts or galleries, and the work, in such cases, had simply to go on from both ends. But as a rule it was quite possible to have either shafts or adits. The fixing of the direction of these, of the latter especially, was a matter of some nicety, but in nearly every case it was quite successful. The number of adits used in any place depended on the ascertained rate of progress in mining for the particular rock in which the work was going on; the object being to have as many adits as would enable all the galleries to meet at the same moment. The adits were, in cross section, about the same size as the main headings, viz., about eight feet square. When the headings met, the tunnels were taken out to full size, and the adits, which were left unaltered, were used for getting rid of the débris from the tunnels.

In blasting the rock to make these adits and tunnels—for every cubic inch had to be taken out by blasting—manual labour only was at first employed. Two gangs of labourers could stand side by side and "jump" holes in the rock face, horizontally. A compound air rock perforator, that had formerly been used for the tunnels at Attock under the charge of some non-commissioned officers and men of Royal Engineers, was sent to Sibi for use on the tunnels at Chappar. But it was found impossible to move this heavy machinery, one piece of which weighed eleven tons, across 100 miles of a roadless and difficult country, and so it never left Sibi. At the same time it was felt that progress with manual labour only was slow and crude, and so a light American machine, called Ingersoll's rock drill, was procured from New York. This was mounted on a sort of travelling carriage with wheels. It was infinitely lighter than the other, but even it required two elephants and a large gang of men to drag it up to Chappar—and one of the two elephants was never fit for any work afterwards. This machine works by compressed air which is conveyed in iron pipes to the various drills. I am sorry I never had an opportunity of seeing this work; it was first used last May and has been, I believe, very successful.

Dynamite and gunpowder were both used in the tunnels in very large quantities, in fact very special arrangements had to be made with the arsenals, and with Messrs. Nobel & Co., the dynamite people, for the amount required. The officers in charge of the tunnel works as a rule preferred gunpowder to dynamite, because the latter shattered the rock into such fragments that it was troublesome to clear away, whereas a big block loosened by gunpowder could be lifted or tipped along with crowbars along the nearest adit over the cliff.

The fuzes used were Bickford's ordinary black and land instantaneous. A few Bickford's subaqueous fuzes were kept in store for use in damp localities. In firing groups of mines, in order to secure simultaneous action, a number of instantaneous fuzes were fastened together in a bunch or knot above end, to which knot was also made fast an ordinary time fuze. The point at the knot was secured by gutta-percha and tin. Such groups of fuzes can either be made up in store or obtained ready made from the manufacturer. The method of using was to put an instantaneous fuze in each mine, and to light the ordinary time fuze. When the latter burned as far as the point the whole of the mines would go off simultaneously, the fire being communicated along the instantaneous fuzes to each mine. There were other arrangements, more or less ingenious, of different kinds of fuzes, but it would be a waste of time to enlarge on this subject further.

In addition to gunpowder and dynamite, blasting gelatine was also used. It is said to have enormous explosive power, but I have had no experience of it myself, and am not aware how it has turned out.

Arrangements had to be made in all large tunnel headings to give light and ventilation. The former could only be given by reflection from a sheet of tin placed outside. Naked lights were forbidden where explosives were being used. Ventilation was conveyed through pipes from large bellows placed outside and kept constantly working.

While on this subject of mining it may be as well to describe the method of blowing up rocks with large charges. It was often desirable to blow out large portions of cliffs where a tunnel was either not practicable or unnecessary. A gallery would then be made about four feet square in section as far into the rock as the line of least resistance required, and then two branches of similar cross section, and somewhat less length, were made at right angles to the entrance gallery. The ends of these branches might be still further enlarged to receive the charges. The proportion of powder required for the charge varied with the nature of the soil, but for most ordinary soils $\frac{1}{10}$ LLR^3 was found to be a formula giving very good results. The gunpowder used on the works was RLG, supplied from the Indian arsenals; it was sent in 50lb. and 25lb. barrels (which barrels, by the bye, came in very usefully for a variety of temporary works). In loading the mines it was found better to take the powder out of the barrels and put in cloth bags, each capable of holding about 10lbs. weight. By this means it could be packed better at the mine head. When all the charge had been loaded up, the powder hose was placed in the centre of each. Ordinary one-foot canvas piping was used for this, the powder poured in as tight as possible. In arranging the train of hose it was customary to lay one length of hose from one charge to the other, and then to have two lengths, one along each of the main gallery and meeting the other hose at the T head. At the points of junction the hoses were nailed together on a small piece of board, and some loose powder scattered over the joint. To protect the hose from the pressure of the tamping, it was placed inside hollow bamboos split in half longitudinally. After the hose had been placed in one half of the bamboo, the other half was laid over it, and the two tied together. Outside the mine the ends of the hose were brought together and nailed on a small board, to which also was fastened a suitable length of Bickford's fuze. Loose powder was also poured over this joint. The tamping of the mines was generally sand-bags, but here and there it was good to build a wall of mud bricks across the gallery, or boulders in clay might be used. It was worth while to take trouble with the tamping; a badly tamped mine always gives poor results. If, however, all precautions were taken the mines were invariably a success.

Electric fuzes were not used, partly because of the uncertainty of their action, and because there were few cases in which a large number of simultaneous mines were required. In no case, either in tunnels or in other mining operations, did an accident occur that could have been prevented by the use of electric fuzes.

Another very important branch of railway engineering is plate-laying, and of the special experience we had on the Sind Peshin line I now desire to say a few words.

The pattern of sleeper sent out to the Sind Peshin Railway is known as Denham and Olpherts' patent. I do not know by whom or on what principle this was selected as the type of sleeper, but it was certainly unsuitable in every way for a mountain railway. The sleeper and chair consisted of nine separate parts, cast iron plates and jaws for gripping the rail, and wrought iron ties, keys, &c., for keeping the whole together and preserving the gauge (*vide Plate* X.). The defects of this type of sleeper are very numerous. In the first place the multiplicity of parts caused endless worry and trouble. Next it was impossible to use the sleeper on bridges, or where check rails were required. Now it is generally laid down that every curve under 1000 feet radius ought to have a check rail, and as two-thirds of the curves on the line are of this description, this practically cuts out the larger portion of the line. And, again, this pattern of sleeper has very little grip on the ground, so that when laid on gradients (and it will be remembered that the greater portion of the line is on the heavy 1 in 45 gradient) there is a strong tendency to *creep*, *i.e.*, be pulled down hill by trains passing over. The last objection to the sleeper is because of the brittle nature of the cast iron. The wandering Afghan or Beluch is a mischievous creature, and thinks the breaking a piece of cast iron by dropping a stone on it, rather a nice amusement. This we have already found frequently by experience. So with this sleeper, constantly patrolling the line will be required to see that no tricks of this sort are being played.

The one advantage of this sort of sleeper is that it is made to gauge, and hence this does not depend on the platelayers. But unfortunately the sleepers sent out for the Sind Peshin line were very badly made, tight to gauge, and of very rough workmanship. And so the one advantage was lost.

The rails used were of steel, 80lbs. to the yard, and double headed. The fish plates were of the latest fashion, coming down over the lower flange of the rail but not below it, and secured by six fish bolts. All the permanent way, rails, sleepers, fish plates and bolts were sent out from England expressly for the line. The fish bolts were very badly made; very few indeed could be screwed home, and the whole of them had to be cut, shaped, and altered in workshops in India.

These defects in the permanent way simply show the absolute necessity there is for careful inspection in every detail before the articles are sent off from home to a distant part of the world. These practical difficulties give an immense amount of worry and trouble, and they could quite well be obviated by a little care in the initial inspection.

A few words with regard to the actual platelaying. It was the wish of the Commander-in-Chief, a wish that was heartily responded to by the Brigadier-General commanding the Pioneer Brigade, that the men of those regiments should be employed as much as possible on platelaying, so as to give them an experience in this branch that would afterwards be a valuable military acquisition. Consequently the two Punjabi regiments were detailed for this work. One regiment would at one time have the platelaying and all temporary works in the immediate vicinity of the rail-head, while the other would be camped near the line a few miles further on, making up the line and banks, and making diversions and temporary bridges. When the rails had advanced some distance beyond the regiment furthest to the rear, *i.e.*, that which has been doing the platelaying, that regiment would strike camp and march some few miles beyond the other. The latter would then take up the platelaying, and the first regiment would take up works ahead. Thus, working alternately, both regiments were exercised in the work required. The men soon learnt what was to be done, and the officers took the keenest interest in their instruction. In one regiment each company in succession was exercised in the manipulation of the rails and sleepers; in the other regiment two companies were kept specially for platelaying, and the other companies were not taught it. The Brigadier-General did not interfere with the arrangements that each commanding officer chose to make in this respect, but he certainly considered the former method the better. There was one Engineer officer told off to be with the working parties, and direct operations. It was his business to notify every morning to the traffic officer at the base what quantity of permanent way material would be required for the next day. With this information, in the morning the traffic officer would load up at the base during the day the required amount of material complete, and have it made up into a train ready to be sent off early the following morning, so as to arrive at the rail-head by the time the men were paraded for work. On arrival the men would empty the train at once. Certain men would be told off to carry rails and lay them roughly parallel to the line; others would bring sleepers, and so on. As soon as the train was emptied it would move back again to the base for any other material duties. The working party would then go on with the laying of the rails in proper fashion, and work at it until it was fit for the passage of an engine the following day. The men worked in a very orderly manner, but there was no regular system of drill, which was, I think, a pity. There might have been some difficulty with the impracticable Denham and Olphert's sleeper, still some simple drill might have helped to accelerate matters with men accustomed to work in unison.

This system of platelaying seems, no doubt, very simple, but it required constant attention to details, and very often hitches occurred which interrupted the progress of the work. Chief among these troubles was the multiplicity of parts in the sleepers. If less than the exact number of each part in proportion to the whole was sent, the work was stopped for want of them. On the other hand, if more than necessary were sent, they got thrown aside, and might be forgotten next day, and then a pick-up train would have to go along and collect all the scattered pieces.

Generally, for military purposes, I think the old-fashioned wooden sleeper is, all round, the best. Soldiers very soon learn how to use it; it is very simple; can be used everywhere, *i.e.*, on bridges, curves, and all sorts of ground; and it comes in useful in a variety of ways besides its ordinary work. Thus temporary bridges of many kinds, scaffolding, staging, water-tank stands, and all that kind of work can be run up very quickly with wooden sleepers, and it may also be used for stockades, and any works of defence that may have to be made for protection of the railway. Its only defect is liability to be burnt, but even that is not so dangerous as the brittle tendency of cast iron sleepers.

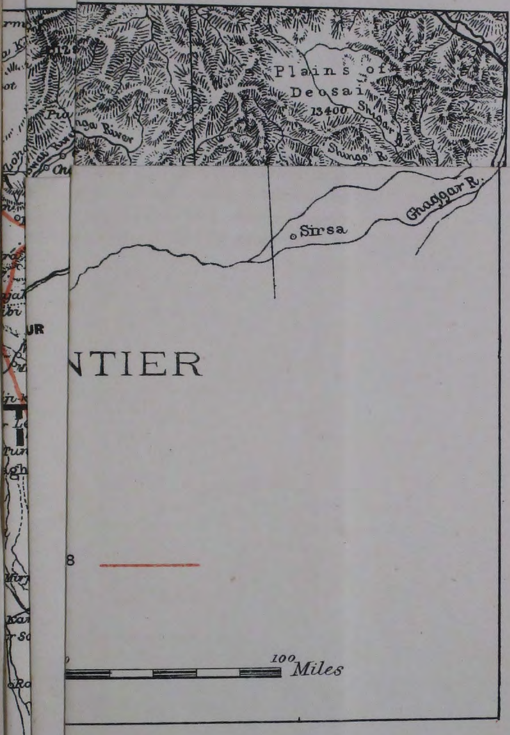
Before concluding, let me just say a few words about river protective works. The violent floods we had last year made the protection of the banks, where exposed to the action of rivers, a question of pressing importance. It is customary to pave or pitch with large boulders banks exposed to water, but it was considered that this arrangement would not be sufficient in many cases. Two further protective methods were employed, both somewhat novel. In one place an arrangement was devised of protecting the toe of the slope with layers of concrete blocks chained together. Three chains were fastened securely to a small girder, which was buried in solid ground beyond the end of the bank on the up-stream side, and which, therefore, served as an anchor. The chains were then passed through empty Portland cement casks, laid in rows at the toe of the bank, and these casks were then filled with coarse Portland cement concrete. The chains thus passed through the centre of each block of concrete, and in order to connect each row or string of blocks, the chains were tied one to the other at intervals by smaller chains. The result of this was to present to the river a great shield, solid and yet flexible, like chain-armour. This protective work stood well in a heavy flood last March.

Another method was carried out on a very large scale by Captains Hoskyns and Whiteford, and consisted in a protection of the largest and heaviest boulders, and over them an enormous network of telegraph wires. The net was first made and laid with its lower edge in a trench at the bottom of the bank. This trench was filled up with boulders, so as to fasten the net below securely. Then all the pitching was duly placed in position, and when all was ready the net was turned over all and securely fastened down at the top. The effect of this great net was to keep the whole mass together. In the event of scour the whole would subside together.

I might say much more about details upon which I have not been able to touch, about concrete arches and culverts, retaining walls, diversions, temporary bridges ; about station arrangements and rolling stock ; but time does not admit of these details being enlarged upon, and I therefore bring my lectures to a close, hoping that they may have given some of my hearers an idea of the work done on the Frontier Railways of India.

G.K.S.M.

Plate I.



Plains of Deosai
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Shigar
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100 Miles

PAPER X.

Joint Report of Col. Rich and Lieut.-Col. Luard to the Inspector-General of Fortifications, on Hilf's System of Railway and the Military Arrangements in Germany for working Railways in time of War.

LONDON, *29th April*, 1885.

SIR,

We arrived at Wiesbaden on the 28th of March. Mr. Hilf is the Engineer of the German State Railways of that district, and resides there.

After going thoroughly into the subject with Mr. Hilf at his office, we arranged to go with him to Limbourg, where the district railway works are placed.

While there we saw the material and the crane used in laying the Hilf Railway, and we saw a rail bent for laying round a curve.

To do this, the flat top of the steel sleeper is tapped with bolt holes, which are placed to suit the radius of the curve; and the rail, which is a light one, takes the required bend as it is bolted to the sleeper.

Mr. Hilf was not prepared to lay any rails, so that we did not see this done.

Having obtained all the information that we could from Mr. Hilf, we proceeded to Berlin, where we arrived on the 3rd April. We called at the British Embassy and on Colonel Swaine, the Military Attaché, next day.

On the 11th April we visited the military railway in the south-west suburbs of Berlin, saw Colonel Golst and Major Flock, of the railway regiment which is stationed there.

There are two railway regiments in the German army, and they are practised in railway laying and working of every kind.

The above-named officers were most courteous, and when we left, Major Fleck, with whom we remained a long time, said he had nothing further to show us—that he had told us everything.

This did not amount to much. He stated that there was no particular system in use in Germany for military railways, and that the Germans had no system of light railway that could be laid quickly for the use of an army in the field.

The Germans use small narrow gauge railways in their arsenals, as we do, and since the Franco-Prussian war three strategic permanent railways have been laid to the Rhine, but no particular form of permanent way is adhered to on these lines.

Major Fleck had laid Hilf's system. He did not particularly approve or disapprove of it.

He stated that, with 24 men of his regiment, he had laid 250 metres, that is, about 278 yards, in $1\frac{1}{2}$ hours; and, when asked how much he could lay under pressure, he said 300 metres in 2 hours. We pointed out to him that this was less than when not working under pressure, but he adhered to his first statement, and the only conclusion we could arrive at was that he had not timed his operations very accurately. We were more convinced of this when we obtained information from the Civil Department of the German State Railways on a subsequent day. Major Fleck thought that a wooden cross sleeper railway could be laid faster than the Hilf system.

On the 13th April we had an interview with two of the civil officers of the German State Railways, Mr. Davies and Mr. Claus; the latter, with whom we spent several hours, is the Chief Superintendent (or Inspector of Railway Construction). He had been many years in railway service. He is an engineer, and had served in that capacity before he rose to his present position. He informed us, that although the German Government had tried many systems of permanent way, with steel, iron, and wooden sleepers, and had kept records of the operations, they had not yet arrived at any conclusion as to which was the best, the cheapest, or the easiest maintained.

Some engineers liked one kind and some another, and reported accordingly. Hilf's system had been used a great deal. When first brought out, the steel sleeper was too light; but Mr. Claus thought that the weight of the section submitted with this report was satisfactory. The cross sleeper had been introduced to prevent the rails sinking at the joints. Since its introduction the rail was inclined to sink in the centre.

He said that good ballast and good drainage was essential to the success of Hilf's system, and that on steep inclines it was apt to give trouble in maintenance. Mr. Claus had not used the special crane in laying Hilf's system, but only an ordinary crane. The crane has undergone some alterations in its arrangements. Five kilometres of Hilf's system was the greatest length that had been laid in six working days, so far as Mr. Claus's experience went. We think this a reasonable quantity, and at that rate 10 kilometres, or about six miles, could be laid in one week, by working day and night.

Major Fleck informed us that the bend in the steel cross sleeper was apt to flatten by use, and that the gauge of the railway was thereby increased and became too wide. This defect has been mentioned in a discussion at the Institution of Civil Engineers.

Mr. Claus does not think Hilf's system a good permanent way for laying on a new formation, but this system has been laid, and is now in use, on 3,907 kilometres, viz. about 2,500 miles, in Germany (Appendix No. 1).

Description of Hilf's System.

The Hilf system consists of a Vignoles pattern steel rail that weighs about 51 lbs. per lineal yard. It is fixed with nuts and bolts to longitudinal steel sleepers that weigh about 60 lbs. per yard lineal.

The rails are laid in lengths of about 30 feet, and are fished with ordinary fish-plates. The longitudinal sleepers are a trifle shorter, and are fixed at each end on the top of steel cross sleepers of similar section to the longitudinal sleepers.

The steel sleeper is half of an octagon in section, somewhat like a saddle, of which the flat top on which the rail is fixed is 180 centimetres broad. The sloping sides are 76 centimetres long, and the two outside flanges are 30 centimetres deep and are vertical.

There is a strong rib under the centre of the flat top to give strength to the whole, and there are four small saddle brackets between the longitudinals and each cross sleeper, to prevent the vertical and centre rib of the longitudinal from cutting into the cross sleeper.

The cross sleeper is bent in the centre, so that the ends may slope upwards, and thus give a tilt inwards to each rail.

In addition to the above there is a steel cross tie in the centre of each 30 feet of rail to keep the line to gauge.

The junctions of the points and crossings on Hilf's system are not laid on longitudinal sleepers, but on cross sleepers of similar section to the longitudinals. The longitudinal sleepers end about 22 yards from the points and from the centres of the crossings.

The permanent way is laid by means of a material train with a specially designed crane. The crane is attached in front, a locomotive in rear, and intermediately are placed one dummy, and about four or five wagons loaded with materials and a small travelling workshop. The train is loaded with long sleepers, rails, and other material, and the locomotive then pushes it to the required spot. Two cross sleepers are first laid by hand at an interval of a rail's length, and the crane then seizes the longitudinals two at a time, to which the rails have been bolted, and places them in position. The train is then pushed forward a rail's length and the process is repeated. In moving forward the train assists the laying by pressing the sleepers firmly into the ballast. A gang of workmen follows the train and completes the work of laying.

Deductions and Opinion of the Relative Merits and Demerits of Hilf's System.—Having duly considered all the evidence relating to Hilf's system, we have arrived at the following conclusions :—

1. That it is a good system of steel sleeper road. We ran over it between Wiesbaden and Berlin for many miles, in many different places, at speeds varying from 35 to 50 miles an hour. We found the motion of the carriages as even, noiseless, and smooth as on any of the other portions of the railway, which is laid with wooden cross sleepers, but we did not think the running as smooth as on the best English railways, though the speed was certainly not as great as that of our express trains.

2. The weight of a mile of Hilf's system is about 200 tons, whereas the weight of the best English systems (Appendix No. 2) is from 322 to 340 tons. But the light 51-lb. rail of the Hilf system would not last like the heavy 84-lb. rail used on English lines, if subjected to a heavy mineral traffic, though the Hilf sleeper would last longer than the wooden sleeper used in this country.

Hilf's system would be more difficult to break up, and would not require such close watching as a wooden sleeper road. In a barren country, where the inhabitants would be tempted to steal wood, it would have advantages.

For these reasons we think it suitable for a country where either a permanent strategic railway is required, on which there would be only a light ordinary traffic, or for India and similar countries, where wooden sleepers do not answer, but it is not suited for a military railway, which requires to be laid very rapidly. For the process of laying is not quick, and there are difficulties in respect of curves, and especially in those of less than 10 chains radius, which difficulties are avoided on a road laid with cross sleepers.

Though not consistent with rapidity, the method of laying the Hilf system makes it largely independent of extraneous labour, and tends to secure uniform progress, consequently it might be usefully employed where labour is scarce.

Mr. Hilf has sent plans of a similar system of lighter construction, and he would propose to lay it on curves of much less radius by making the longitudinal sleepers much shorter. This light system has never been tried, but the method of laying it is the same as the heavier line. We doubt if it would answer, as the light longitudinal sleepers would be apt to get bent, and would then become useless.

Having considered all matters connected with the question on which we have been required to report, and having spoken on the subject with several persons connected with railways of all descriptions, which have been used for iron-works, slate-works, sugar-works, and other commercial purposes, we have no hesitation in stating that the best form for a military railway which requires to be laid speedily is a cross sleeper railway of a narrow gauge (Appendix 3), and by preference, of the metre gauge, as this is largely used in India, and therefore materials for permanent way and stock, on that gauge, could be obtained at short notice. The sleepers can be of wood, iron, or steel, as may be most easily obtained. The rail in this case can be of light section.

A railway of this class would weigh about half what the Hilf railway does, and the parts being comparatively light, they can be easily handled and carried by men if larger transport were not available.

It has been proved by experience both in England and in India that railways of this class can carry engines of sufficient weight, and stock of sufficient dimensions and strength, to deal with all kinds of guns and war material which would accompany an army in the field, and such a railway is not so liable to be injured by being laid on rough ground or on sharp curves.

We have the honour to be, Sir,

Your obedient, humble servants,

F. H. RICH, Colonel, R.E. (Retired),
Inspector of Railways, Board of Trade.

C. H. LUARD, Lieut.-Colonel, R.E.

N.B.—On my return journey to London I met one of the engineers of the Chemin de Fer du Nord; he told me that Hilf's system had been tried on that railway and on the Belgian State Railways, but that it had not been liked, and had all been taken up.

I wrote to the chiefs of these railways to know whether this was the case, but I have received no replies to my letters up to the present time.

F. H. RICH.

I have since received a reply from the Chief of the Belgian State Railways stating that the above is true, and that, from experience, he does not approve of Hilf's system.—F. H. R. 25.6.85.

List of Documents accompanying.

1 Appendix No. 1. List of Railways on Hilf System.

1 Appendix No. 2. Comparison of Weights of the Hilf and English Systems.

1 Appendix No. 3. Account of Line laid on Metre-gauge in Tirhoot, India, in 1874.

APPENDIX No. 1.

LIST OF STATE RAILWAYS AND PRIVATE RAILWAYS UNDER ADMINISTRATION OF STATE, AND PRIVATE RAILWAYS UNDER THEIR OWN ADMINISTRATION LAID ON THE HILF SYSTEM.

I. State Railways.	Length laid. Kilometres.
(1) Alsace-Lorraine	655·92
(2) Prussian State Railways:	
(*a*) Direction of the Royal States Railway, Berlin .	498·46
(*b*) Royal Railway Direction, Bromberg . .	206·70
(*c*) " " Hanover . . .	382·48
(*d*) Property of the Princedom, Schomberg . .	3·37
(*e*) " City of Bremen . . .	13·27
(*f*) District of Royal Railway Direction, Frankfort	736·75
(*g*) " " " Magdeburg	20·35
(*h*) Cologne, Right Bank	190·64
(*i*) " Left Bank	413·73
(3) Bavarian State Railways	359·33
(4) Wurtemburg State Railways	26·47
(5) Baden State Railways	6·11
II. Private Railways under State Administration.	
(6) Bergisch-Markisch Railway	3·08
(7) Netherlands, Westphalian	82·28
(8) Upper Schleswig Railway	0·19
(9) Breslau-Pozen-Glogau Railway	4·97
(10) Rhine neighbourhood	0·88
III. Private Railways under their own Administration.	
(11) Berlin-Hamburg Railway	24·44
(12) Thuringian Railways	136·87
(13) Hené Ludwig Railway	123·10
(14) " Palatinate	2·39
(15) Eisenberg-Cronen Railway	7·88
(16) Kuhla Railway	7·77
Total . . .	3,907·73

Kilometres, or 2,500 miles.

Note.—This does not include renewals of old cross-sleeper roads by the Hilf system.

APPENDIX No. 2.

COMPARATIVE TABLE GIVING DETAILS AND WEIGHT OF HILF'S AND ENGLISH MAIN LINE SYSTEMS.

Gauge in each case 4 ft. 8½ in.

No.	Hilf's System	Weight
		lbs.
2	Rails, 29·7 ft.	1,021·6
2	Long sleepers, 29·5 ft.	1,157·6
1	Cross ditto, 8·5 ft.	167·9
1	Cross tie and fastening	17·1
64	Clips and bolts	46·4
48	Washers and nuts	16·7
8	Double clips near fish-plates	10·9
2	Fish-plates	33·6
16	Fish-plate bolts and cross-sleeper bolts	19·3
8	Clip fastenings for long sleeper, inside and out	10·3
4	Saddle irons and bolts	18·2
156 parts	Total	2,519·6
	Say	2,520
	Per yard	255 (about)
	Per mile	200 tons

No.	English System	Weight
		lbs.
2	Rails, 30 feet or 10 yards, at 82 lbs. per yard	1,640
11	Sleepers, at 140 lbs. each	1,540
22	Chairs, at 40 lbs. each	880
66	Spikes	57
22	Keys at 1·36 lbs.	30
4	Fish-plates at 35 lbs. per pair	70
8	Fish-plate bolts at 7½ lbs. per ½ doz.	10
135 parts	Total per 10 yards	4,227
	Per yard	422·7
	Per mile	322 tons

N.B.—When the rails weigh 84 lbs. and the chairs 45½ lbs., about 10 tons per mile would be added to the above, making a total weight of about 340 tons per mile.

APPENDIX No. 3.

ACCOUNT OF LINE LAID ON METRE-GAUGE IN TIRHOOT, INDIA, IN 1874.

In 1874, Colonel F. S. Stanton, Royal Engineers, laid a famine line in the province of Tirhoot, when every exertion was made to secure rapidity, at an average rate of over one mile a day, the maximum length of plate-laying done in any one day being two miles. The last 46 miles of the line were completed in 41 days.

The following extracts from Colonel Stanton's Report show the method of procedure :—

"The line was first ranged out and the curves put in by the Engineer in charge; then a gang of men under an overseer was sent forward to clear trees, and to level and dig up the surface of the ground in order to give the sleepers an even bearing.

"As soon as the road was ready for the sleepers, a gang of men distributed them along the line, followed by another gang which ranged them in proper line and spaced them.

"On the arrival of a train with materials at rail head, the Sappers and Pioneers were told off at eight to each pair of wagons to unload the rails, sleepers, &c., the unloading of a train taking from half to three-quarters of an hour.

"The sleepers were then carried forward, either by coolies or on carts, and placed as noted in a preceding paragraph, and the rails were similarly dealt with, being deposited in pairs alongside the sleepers; the fastenings were placed on trolleys and moved forward as the rails were laid, a small quantity distributed ahead by boys specially told off for that service.

"The rails used were flat-footed, weighing 40 lbs. to the yard.

"They were jointed with fish-plates and spiked to cross sleepers (weighing 50 lbs. each). The rails were mostly 24 feet long, requiring nine sleepers to each pair of rails. The sleepers being spaced and the rails laid alongside, the plate-laying gang commenced their work. A certain number (four to a rail) lifted the rails on to the sleepers, placing them butting one on another on each side. A gang of men then followed, distributing fish-plates and bolts at each joint, when the men told off for the purpose immediately attached the fish-plates at the rail joints, fastening them, however, with only two bolts instead of four. These men were closely followed by the auger and spike men, who, with their rail gauges applied, spiked down the rails to the sleepers at the joints, thus spiking five out of the nine sleepers to a rail.

"Following these men came a party with levers to straighten the line, after which operation some coolies filled earth between the sleepers and partially packed them.

"This first large gang of platelayers was then followed by an entirely separate gang, who completed the joints and spiking, and properly packed the road."

From the description given, it will be seen that the train did not do its own distribution, but that extraneous carriage and labour were freely employed, and that the speed with which it was laid depended upon their ample supply. But the Hilf system of laying, described in the accompanying report, is so largely independent of local resources that, notwithstanding their deficiency, it would tend to secure a constant rate of progress. The cross sleeper road is, therefore, the more quickly laid system where labour is abundant. The Hilf system has advantages where labour is scarce.