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PAPER I.

THE LATEST DEVELOPMENTS OF PRACTICAL TREATMENT OF SEWAGE.

By W. C. Tyndale, Esq., M. Inst. C.E., F. San. Inst.

I am glad to have been afforded an opportunity of speaking to you on the subject of this lecture for two reasons.

In the first place, I believe that I may be able to supply a want which I have often felt myself of a short and concise account of the origin, history, rationale, and practical application of the development of the natural purification of sewage by what is generally termed biolysis. It is a fact, I believe, that although so much has been written on the subject in the various forms of articles, papers, and exhaustive treatises, no condensed yet comprehensive exposition of the subject exists which enables a ready grasp of the subject to be obtained, and the more intricate and scientific phases, which are dealt with in such books as Rideal's *Sewage and Sewage Purification*, to be appreciated.

In the next place, I conceive that in time to come it may be my pleasure to collaborate with you in the practical application of the subject, when we shall doubtless mutually derive benefit in being able to approach the subject from the same standpoint, and feel that it is somewhat of a link between us.

I trust that what I shall say this afternoon will not be considered too elementary, but in deciding on the lines which the lecture should follow, I thought that were I to try to bring within the time allowed for this lecture all the history and details of this intricate subject, I should be attempting the impossible, and that therefore I could not do better than carry my mind back to the time when the latest developments of the practical treatment of sewage was somewhat nebulous, and to put before you such information as I should then myself have been most glad to possess.

The title of the lecture confines me to consideration of what is now generally termed the biolysis of sewage, as on no other lines than those by which sewage has been purified by bacteria has any development been made. It is right that this should be so, for the biolysis of sewage follows nature's own methods, while other systems, except that of land treatment, worked more or less on lines opposed to natural action, with the result that they have proved to be failures.

To within a few years ago the methods usually adopted for purifying sewage on anything like a large scale, as you doubtless are aware, were those of chemical treatment, followed by application to land in the form of a sewage farm.

The arrangements of the treatment of the sewage prior to its application to land consisted generally of the provision of strainers, by which the grosser solids and all large inorganic rubbish were excluded, and settling tanks, in which the sewage either rested or through which it passed very slowly after receiving certain proportions of chemicals.

In these tanks a large part of the solids were precipitated in the form of sludge, and from them the liquid passed on to the land.

This was accepted as the best that could be done, and everywhere, except at sea-board towns and in other exceptional places, new schemes were based on these lines.

The system involved great expense, not only primarily in buildings and land, but annually in maintenance.

Among other matters the by-product of sludge from the precipitation tanks has always been a very great difficulty on account of the largeness of its volume. As it comes from the tanks it contains about 90 per cent. of moisture, and has to be passed through presses under compressed air, or dried in some other way before it can be handled. Even in this condition it is of considerable bulk, and there is difficulty in getting rid of it, as, although it was originally supposed to be of considerable value to market gardeners, farmers, and others, its manurial value compared with its bulk is not worth the cartage even when given away.

It is not meant to imply that the application of sewage to land is working in the wrong direction, as that would be to create a wrong impression, but what is meant rather is that the methods adopted for rendering sewage fitted for land treatment were, in the light of present knowledge, at best but clumsy, while if they did not actually retard the action courted by land treatment, they afforded little help in that direction. The gigantic proportions to which the area of land required attained, to meet the necessities of big towns, is, in the case of sewage farming, also a very serious matter.

The history of the breaking down and purifying of organic matter as exemplified by nature is as old as that of life on this earth, for it is by means of organisms that nature has always decomposed and reduced to its original element the organic matter which from time to time is being received into the surface of the ground. But the process represented by the employment of nature's action to meet man's requirements is only of recent growth. The general belief was that the breaking up of organic wastes was carried out by the direct action of oxygen, and this held its ground until the experiments of Pasteur and Warrington showed that the changes were, for the most part, due to the life processes of micro-organisms. The discoveries with regard to fermentation by Pasteur, and of nitrification in cultivated soils by Warrington, however, only had a general bearing upon the question of sewage disposal. Subsequently the Massachusetts State Board of Health made a long series of experiments upon the downward filtration of sewage, which showed that the same process that occurred in soils could be carried on in artificial filters; beyond this point, however, no direct attempts were made to apply the discoveries to the purification of sewage.

It would appear that in this matter, as in the case of many other discoveries, developments were due, not to one person only, but to several, each, however, acting independently and without any knowledge of the other's investigations.

If priority be due to anyone it must be given, perhaps, to Mr. Scott-Moncrieff, C.E., who in 1891 commenced a series of experiments in apparatus especially designed to prove the theories which he had conceived; but somewhere about the same time Mr. Dibdin, then Chemist of the London County Council, made between the years 1891 and 1895 a series of trials upon partially clarified sewage at the Northern Outfall at Barking.

Closely following on these also Mr. Cameron, C.E., of Exeter fame, commenced experiments with an installation which was the forerunner of the renowned "Septic Tank Process."

What became known of the results of Mr. Scott-Moncrieff's and Mr. Cameron's experiments, and the publication of Mr. Dibdin's reports to the London County Council by that body, gave a great impetus to the sewage purification problem, and numerous engineers and chemists set about to find out how best and under what conditions nature's action might be brought to the highest state of efficiency in the simplest way, and within the smallest compass, so as to be of really practical use.

Before proceeding to explain in detail the various systems by which it has been sought to apply the principle, it will be well to consider what is the exact object to be accomplished, and what, broadly speaking, may be accepted as the rationale of the biological process.

First, as to the object which it is desired to accomplish.

Sewage is a very complex material containing highly putrefactive organic matter, both solid and liquid, and what has to be effected is to remove, by bringing into solution, the solid portion of the organic matter, and then bring about such a change in the organic matter in liquid form as will render it non-putrefactive or not liable to change.

Secondly, as to the rationale of the biological process, there are two distinct stages, viz. :—

(1), The breaking down, or liquefying of the organic matter; and (2), the nitrifying or mineralizing of the results of the first stage.

With regard to the term nitrifying, it would perhaps be better to use the more general term oxidizing, as, besides the nitrification of the organic compounds in the presence of oxygen, oxidization of the organic carbon also takes place. I prefer, however, in the present instance to retain the word nitrification, as it refers to the change in organic compounds, which it is the main object of the second stage of the process to effect.

The changes produced in these stages are effected by means of micro-organisms in mixed communities, existing either in the organic matter to be treated or in its surroundings.

To classify these organisms broadly, it may be said that they consist of what are known as "anaerobics," or those which *can* exist without oxygen, and "aerobics," or those to which oxygen is necessary. The anaerobics are very numerous in sewage, and are suited to liquid which contains little or no oxygen, but which may at any time become oxygenated.

Both classes of organisms share in the work performed in the first stage, viz., the liquefaction of the solid organic matter, but the aerobics alone are capable of producing nitrification or final mineralization and restoration to its original elements of the organic matter liquefied by the non-nitrifying organisms.

When passing from the liquefying stage to the nitrifying stage, the organisms which are solely anaerobic having effected the object required of them die out, and are succeeded by those living only in the presence of oxygen, and which produce nitrates or nitrites.

From the foregoing it will be understood that the conditions in which the two classes of organisms exist are very distinct, and that to obtain the best results the arrangements of a system should be such that the conditions are so favourable to the particular organisms concerned, and are arranged in such sequence as to exalt the natural action and produce a corresponding rapidity and completeness in the results.

It would seem that Mr. Scott-Moncrieff was the first to realize the advantages to be gained from a preliminary liquefaction of the organic matter by fermentation, carried on in a separate apparatus, and his installations all provided for a proper sequence of liquefaction and nitrification.

Other installations embody the principle to a greater or less degree, and although some of them present no clear line of demarcation between the stages, they do so sufficiently to show that the principle is recognized as a right one. The action in the latter stage is similar to that which occurs in the surface of the ground.

Proceeding now to consider the details of the systems previously referred to for bringing about the desired changes and purification of sewage, we may first consider Mr. Scott-Moncrieff's apparatus.

(1). Scott-Moncrieff's Installation.

This consists, first, of a liquefying or digesting chamber (*Fig.* 1, *Plate* I.), which may be described as an open tank, filled with large stones, through which the sewage, entering at the bottom, passes upwards and onwards continuously, but sufficiently slowly to be acted upon by the liquefying organisms, which form dense colonies in the nidus formed by the stones, and which, under the favourable conditions presented to them, increase in proportion to the work required of them.

The result is that the solid organic matter is liquefied, and an effluent, which is practically without solids in suspension, passes on. The bottom of the chamber A is formed in the shape of a channel covered by an iron grating or an arch of perforated brickwork, the object being to keep back from flowing into the interstices of the tank all the coarser solids which might choke the bed, and to retain them below till broken down by the bacterial action. The tank is constructed to contain at least a day's sewage after deducting for the space occupied by the matrix; so that, roughly speaking, the sewage occupies 24 hours in passing through the tank. The outlets of the tank consist of weirs or numerous holes discharging into side channels, and they are only a few inches below the inlet, so that neither is any great disturbance caused in the contents of the tank, nor is an appreciable fall lost through the tank. This constitutes the first stage of the process. The second stage is conceived with a view to placing the liquid sewage under such favourable conditions that the nitrifying and highly aerobic organisms will multiply similarly to the organisms producing liquefaction, and complete the process by nitrification. Accordingly the effluent of the chamber just mentioned is conducted through a series of flat beds (B, *Fig.* 1) or trays containing filtering media, placed one above the other, and with intervening air spaces of a few inches between them. The liquid flows over a perforated surface, through which the sewage trickles by means of numerous holes on to the uppermost tray below; thence it drips to each succeeding tray in turn, and flows away over a cemented surface to an outlet. Thus the sewage is made to meet, under the most favourable conditions of aeration, the organisms of nitrification. The latest installation on this principle has been erected to deal with the sewage of Caterham Barracks, and has proved successful. The analyses which have been made, not only on behalf of Mr. Scott-Moncrieff by Dr. Rideal, but by analysts on behalf of the War Department, show that not only is the effluent sufficiently stable to preclude subsequent putrefaction, but that the nitrification is very great. It is, in fact, greater than the necessities of the case demand.

(2). Dibdin's Process.

Mr. Dibdin's process, as previously explained, dealt with clarified sewage, viz., with sewage which has been subject to chemical precipitation to get rid of the organic matter in suspension. Subsequently, however, at Sutton in Surrey, Mr. Dibdin, who was Chairman of the District Council, instituted some experiments on a large scale with crude sewage, these experiments afterwards developing into the provision of a permanent installation. The arrangements are as follows (see *Fig.* 2, *Plate* I.):—

Large open beds A, filled with rough material such as coke, burnt ballast, or other similar material, are provided of sufficient size to contain at least a day's sewage.

These are called the "primary" beds. At a lower level are provided similar beds B, but containing finer materials; these also are capable of containing a day's sewage. This series of beds are called the "secondary" beds. The process adopted of applying the sewage is based on that which was shown by the experiment at Barking to give the best results. It is as follows:—

The sewage, after being strained of all coarse matters, is discharged into the primary beds in succession, and in each bed the sewage is allowed to rest for a space of about a couple of hours; it is then released into the secondary beds, where the same process is followed. On each bed becoming empty, it is allowed to remain so for a few hours. The cycle, therefore, in connection with each bed is that of filling, resting full, emptying, and resting empty.

I may here mention that this method of applying sewage to beds intermittently aerated is now always known as the "contact" system, as distinguished from the method of applying it continuously, in the form of a raining down or spraying application, to filters, specially and always aerated.

In the above process the primary beds represent more or less the first stage, or the liquefying stage, and the secondary beds the nitrifying stage of the process. The arrangements have been worked for some years at Sutton with satisfactory results, and they have also been adopted at numerous other places throughout the country. The results, it is believed, invariably have been, if not the best, at any rate sufficiently good for the purpose for which the installations have been erected.

(3). Septic Tank.

Mr. Cameron's installation (see *Fig.* 3, *Plate* I.), known universally as the Septic Tank System, consists in providing a close chamber or cesspool A, exalted by the name of Septic Tank. This tank, like that of Mr. Scott-Moncrieff's, is made to contain about one day's sewage, but no rough stones or other material are provided to form a matrix; its depth is never less than 6 feet, the other dimensions varying to suit the capacity required.

The inlets B and C are turned down some 18 inches into the liquid the tank contains. The object of this is to avoid disturbance of the scum which forms on the top of the contents, and which is a result of fermentation, if it does not actually assist in the fermentation which takes place. It closely resembles the barm which accumulates on the top of new beer when undergoing fermentation. The inlet and outlet are through a horizontal pipe slotted throughout its length, so that the current, though an almost imperceptible one, may pass as much as possible through the whole body of the contents, and not in a more or less direct line from inlet to outlet. The second stage of the process is effected by carrying the sewage into contact beds D, similar to the "secondary" beds of the Dibdin system, and these are worked on the same principle by the cycle of filling, remaining full, emptying, and remaining empty.

The installation which was put down at Exeter some five or six years ago to deal with the sewage from a small outlying portion of the town has worked uninterruptedly to the present date, and continues to give good results, with absence of bad odours and a minimum of trouble. See *Fig.* 4, *Plate* II., which represents the plan of the original Exeter installation.

The success which attended this installation in the earlier days was followed by similar small experiments in other towns. On the question of the sewage disposal of the town of Exeter cropping up, the process was recommended for adoption to deal with the sewage of the whole town, and after enquiry held by the Local Government Board, it was passed for adoption subject to certain conditions as regards pecuniary responsibility. The system has made its way so thoroughly that I believe at the present time there are in this country alone some 150 or 200 installations either working or in progress.

(4). Ducat.

One of the earlier systems, and one which, though based on the principles of those previously mentioned, but on different lines, was that adopted by the late Colonel Ducat, R.E., and patented by him.

It consists of an aerated filter only, constructed in the following way :—

A chamber 8 feet in depth, and varying in area according to the amount of sewage to be dealt with, is constructed with a cemented platform, and with walls composed of agricultural drain pipes, all built in as "headers," and slightly sloping downwards towards the interior. The walls, of course, are strengthened by piers at intervals according to their length. The bottom course of the walls consists of header bricks built open so as to allow a free passage for the liquid to run out into a channel constructed all round in the cemented platform. The filter bed is formed of a layer of large stones, above which are several layers of coke, each about 18 inches in depth, which are separated by thin layers of large stones to give aeration. The top portion of the coke is large, that below decreasing in size in succession. In this way a bed 8 feet deep is formed.

The sewage is applied as finely as possible over the whole surface of the bed by distributing troughs placed 1 foot apart and having notches in the sides from which the sewage rains down on the bed, and is thus presented in a favourable way to the organisms thriving in the presence of oxygen.

The distribution of the sewage may also be made by tipping troughs, which cause the sewage to fall in splashes over the surface, and this method is adopted in the latest installations.

The filter as arranged forms a first-rate nitrifying bed, but, as will be seen, it affords no opportunity at all for effecting biolysis in stages. It would seem that, having in mind what has previously been said as to the advantages of providing arrangements to facilitate the two very distinct stages of liquefaction and nitrification, a system which aims at combining a liquefying and a nitrifying bed in one must be under certain disadvantages. In any circumstances the sewage must be carefully strained. The experiments of the Massachusetts State Board of Health show that crude sewage cannot be dealt with in a filter containing fine material, but requires to be passed through large stones, which have to be removed and cleaned at intervals of time varying with the nature of the sewage. However this may be in the case of Colonel Ducat's filter, it is understood that it has been installed in one or two places with satisfactory results. In the case of the only installation which I have seen, and which certainly was giving good results, the sewage was that which had travelled a very long distance through the sewers, and appeared to have lost much of its solid sewage by bacterial action in the sewer itself, so that the clogging matter was in a great measure absent.

The foregoing systems are the prototypes of the various installations in use. On the lines of these, very numerous methods of giving effect to the principles have been adopted.

The feature which has been most adopted is the improved cesspool, or liquefying, or Septic Tank, as it is now called. The very great benefits derived from a liquefying tank have been so far recognized that it has been generally adopted, not only in conjunction with contact beds similar to those of the Septic Tank Syndicate's arrangements, but in conjunction with land treatment, and also to prepare sewage for aerating filter beds of all descriptions. One feature which specially recommends it is that not more than a few inches fall is lost by its adoption. The fact that the use of a liquefying tank by breaking down solids and resolving them into gas and liquids practically annihilates the sludge difficulty is a feature of invaluable importance. It also breaks down the cellulose or glutinous matter of the sewage, thereby removing much of the matter which interferes with the absorptivity of land, at the same time retaining all that is of manurial value, and preparing it for the more easy assimilation by plant life. We therefore see numerous installations at the present time having as a feature a liquefying tank, to be followed either by contact beds, or filter beds on the raining down or spraying principle, or by land treatment only.

These tanks are generally covered in, but in the case of large tanks, where the covering is a matter of some cost, experiments have been made to ascertain whether the leaving of the tanks open would in any way prevent the proper bacterial action. The trials which have been made so far would seem to show that an open tank will work, to all intents and purposes, as well as a closed one. Possibly an explanation of this is that the thick leathery barm which is formed on the top of the liquid has the effect of excluding light and air almost as completely as a proper cover. As against the open tanks, it would seem that the covered ones must be productive of a more even temperature, and consequently more conducive to bacterial action, and also that there is greater freedom from smell.

The success which attended Mr. Dibdin's principle of dealing with sewage in contact beds has led to these being much used throughout the country. The ease with which these beds can be constructed, and very often the cheapness of them, as is the case in clay districts, where they may simply be dug out in the land, are doubtless points in their favour.

The application of sewage to contact beds may in the case of large installations be effected by manual labour, such as in the case at the Curragh Camp (*Fig.* 5, *Plate* III.), where a series of small beds, attended to by the man in charge, are provided for a day's sewage, and large beds are provided to take the night flow, when, of course, the attendance of a man could not be expected. The difficulty of regulating the contact, however, is, in the case of small installations, overcome by various ingenious devices.

The arrangement adopted by the Septic Tank Syndicate is that by which certain valves are opened, while others are closed by means of tipping buckets. A somewhat similar device is manufactured by Messrs. Stone & Company, of Deptford, while Messrs. Adams & Company, the hydraulic and sewage engineers, effect the cycles by means of siphons.

Mr. Scott-Moncrieff's method of raining down the liquefied sewage on open material, and thereby giving the greatest assistance in the oxidizing stage of the process, has been so far appreciated that it has been imitated to a great extent, and filter beds so-called may be seen in many places to which the sewage is applied by raining down, or by spraying. The methods adopted are very numerous. In the earlier days they took the form of fixed troughs (see A and B, *Plate* IV.) laid over the filters, from which the sewage dripped at various points. Latterly, however, great improvements have been made in this respect.

The chief of these is that adopted by Mr. Stoddart, County Analyst, of Bristol, and it is worthy of more than passing comment, as it involves arranging the filter on somewhat different lines from those generally adopted. To deal with this latter question first. The filter consists of large material either enclosed within perforated walls, as in the case of Colonel Ducat's filter, or merely as a shaped heap with sides sloping to meet the angle of stability required by the material (see *Figs.* 6 and 7, *Plate* V.). All round is a channel to intercept the outflowing effluent. Over this bed is placed corrugated-iron sheets A, A, resembling ordinary roofing sheets, but the corrugations are **V**-shaped, thereby securing greater rigidity. These are perforated by small holes all along the bottoms of the grooves, and by slots across the ridges. Each of the bottom perforations is fitted with an ordinary clout nail fitting loosely. These corrugated sheets are connected with a main channel containing sewage from a septic tank. Mr. Stoddart accepts the septic tank as the best means of liquefying sewage and fitting it for the second stage, with which only his filter is concerned.

The action is this:—The sewage from the main channel flows evenly into all the grooves of the corrugated sheets. At first it issues only from the bottom perforations and drips from the ends of the clout nails, but as these perforations become clogged it flows out from the slots across the ridges, and running down outside by capillary attraction, reaches the projecting ends of the nails and continues to drip from them. The nails and slots are very closely situated, so that the sewage becomes very finely divided, and rains all over the beds in a thick shower of big drops. Viewed horizontally below the corrugated sheets, it presents the appearance of rainfall during a thunderstorm. This method enables every particle of the material to be rendered serviceable, so that the sewage is presented to the surfaces of the stones or nodules, of which the bed is composed, in the form of the finest film, and exposing it with ample aeration to the action of the organisms forming a nidus on the nodules. It will be realized from this description how large a quantity of sewage may be dealt with in a small compass, and the results are proportionate, for whereas in the case of other filter and contact beds a volume of about 200 gallons per square yard is considered a sufficient allowance, Mr. Stoddart successfully deals with as much as 1,000 gallons per yard in a bed 6 feet deep, or 500 gallons per yard in a bed 3 feet deep. From this it will be gathered that the quantity is regulated per cubic yard and not to the superficial yard, and this is what Mr. Stoddart contends is the proper way to estimate volumes dealt with on his principle. *Fig.* 6 represents a filter, built at Horfield, near Bristol, dealing with about 130,000 gallons of sewage per diem. *Fig.* 7 shows a similar filter dealing with 1,300 gallons per diem.

The spraying of sewage over filter beds has been effected in several ways. One system is by arranging large pipes along the sides of the filters or sections of the filters, having junction pieces at every 2 to 3 feet, from which perforated pipes are carried across the bed. From the perforations the sewage spirts in numerous sprays, and so fairly covers the beds. Another system of spraying (see *Fig.* 8, *Plate* VI.) is by means of revolving arms attached to a central pipe or trough AA bearing on pivots, and from the perforations in the sides of the arms the sewage spirts; at the same time the recoil action of the jets causes the whole to revolve. The head of sewage is given either by a controlling valve B situated in a regulating tank C, or by means of an automatic siphon. I cannot explain the action more clearly than by saying that the arrangement closely resembles the ordinary garden sprinkler, which is no uncommon sight in suburban gardens.

A good deal of controversy has arisen as to the relative advantages of double contact beds and a liquefying tank with continuous filters.

The advocates of the contact system maintain that whereas the final object is the oxidization of the sewage, the tank deprives the sewage of any oxygen it may contain, and induces a putrefaction diametrically opposed to the changes which are courted in the nitrifying stage, also that any liquefaction of the sewage, and it is agreed that liquefaction is necessary, is effected by the mixed organisms in the primary beds.

It is also maintained that whereas with continuous filtering the whole of the exposed surfaces of the materials cannot be utilized, in contact beds every cubic inch of the whole bed does its work; also that the whole mass is regularly and completely aerated by emptying the filter from below, whereby air is drawn into the interstices.

As against this the advocates of continuous filtering say that the first stage requires practically no oxygen, and is actually hindered by it, and that in the second stage, in which the organisms require ample oxygen, the conditions in contact beds alternate between anaerobic and aerobic, producing conditions so unfavourable that the maximum efficiency is never attained; that in the case of continuous filtration on proper lines the finest possible layer of liquid travels over an extended surface charged with the special organisms and continuously exposed to the air; that the food supply to the organisms is constant and regulated; that there is an abundant and constant supply of oxygen; and that the products of the life processes of the organisms are as constantly removed.

I am not able to enlarge on, or discuss, all the pros and cons put forward by the two contending parties, but taking a common sense view of the matter, if, as appears to be the case, the organisms concerned are of very different orders, and that it is desirable that the conditions should be as much as possible favourable to the different micro-organisms concerned, it seems to stand to reason that those installations which the most nearly comply with the requirements are the best. Moreover, it is a fact that among all the numerous methods to effect the desired object, those which most clearly define the liquefying and the oxidizing stages, when dealing with ordinary sewage at any rate, have produced the best results.

"Oxygen Sewage."

I must not omit to mention a process of sewage purification (see *Figs.* 9 and 10, *Plate* VII.) which, although bearing little resemblance to that which we are accustomed to look upon as the biological process as exemplified by the installations we have been considering, yet is a biological process, is based on sound principles, and effects its objects by the same means. The process is that originated by Dr. Adeney, the celebrated chemist and bacteriologist. It consists in the addition to the sewage certain chemicals. The process, therefore, may be termed a chemico-bacterial process. These chemicals, unlike others one is accustomed to meet with in connection with sewage, which are antiseptics and retard putrefaction, are not antiseptics, but assist putrefaction by encouraging biological action.

The chemicals used are (*a*) oxynite mixed with a little lime, the former a substance composed of compounds of manganese, and (*b*) nitrate of soda.

The action in the process is as follows:—Firstly, the manganese hydrate, which is formed when oxynite comes into contact with sewage, parts with its oxygen and becomes manganese carbonate. This action takes place under the influence of micro-organisms, and the liberated oxygen is used by them. In this way a healthy fermentation is set up; in other words, the organic matter is resolved into its constituents, while inoffensive gases are liberated instead of offensive ones.

The second part of the process consists in adding nitrate of soda to the completely liquefied sewage. Its purpose is to induce a healthy aerobic fermentation, in which the bacteria, being able to abstract sufficient oxygen for their multiplication and development, break down the organic impurities in solution, and convert them into simple bodies incapable of further fermentation.

It will be seen from this description that, although brought about in a different way, the principles are the same, viz., the hydrolysis of organic matter by healthy fermentation, and the oxidizing of the non-precipitable organic impurities.

The diagram shown explains the usual arrangement. For an ordinary sewage the proportions of chemicals used are as follows:—

Oxynite	29 grs.	per gallon	of sewage.
Lime	4 ,,	,,	,,
Nitrate	6 ,,	,,	,,

I have not examined any installation of the process, but one or two have been put down in Ireland, where the patentee lives, which appear to have been quite successful.

The working of the apparatus is as follows:—The sewage is screened at A, after which it passes under a water wheel at B, which works an apparatus containing the chemicals, and admits them proportionately to the flow into the proper tanks, the oxynite into the first or settling tank, and the nitrate of soda into the nitrifying tank. The sewage is then admitted into any pair of the settling tanks C1, C2, and C3, leaving one always idle for cleaning purposes. The sewage then passes to tank C4, into which the nitrate of soda is also passed, and here the nitrifying action takes place, and the sewage passes away through the overflow outlet. The centre tank D receives the sludge from C1, C2, and C3, and is filled with a lifting apparatus to raise the sludge (see Section *Fig.* 10).

The chief advantage the process seems to possess is that it can be used where there is practically no fall between the outfall drain and a stream, or other watercourse into which the final effluent must run. The disadvantage attending the process would appear to be that it depends for its efficiency on the constant delivery of the chemicals used. With proper attention no failure in this respect would occur, but should it do so it is understood that within a very few hours all purifying action would cease. Still there are occasions where it might be worth while to run the risk of a temporary break-down to secure the advantage above mentioned.

A question which may be asked is what effect has rainfall on the various arrangements which have been described? This is a very natural enquiry to make, considering the disproportion which exists in many places between the dry weather flow in the sewers and that of wet weather, specially in times of heavy rainfall.

In the case of towns, the works for which are paid for from public funds, borrowed under Government sanction, the Local Government Board lay down the rules that a system should be capable of fully treating as ordinary sewage a volume of sewage and storm water equal to three times the dry weather flow, and of dealing with the excess of storm water up to six times the dry weather flow, either by passing it through a special and separate storm filter, or by delivering it on to a special area of land. In the case of War Department property, the drainage systems are either on the separate system, or can be made so much so that such excessive flows as those just mentioned need not occur.

There must, however, be a limit put to the quantity passing through a biological installation, on whatever principle it may be devised. The Septic Tank Syndicate meet the case by forming the outlets through their tanks of such diameter that when the flow into the tanks exceeds a certain volume the sewage heads up in the tank, and is partly stored up in it while passing away at a regulated speed, till the original level in the tank is restored. Mr. Scott-Moncrieff also restricts the flow of sewage by contracting the outlet and using his tank somewhat in the nature of a regulating tank to meet excessive flows. In the case of bacteria beds, it will be recognized that, on account of the different methods in dealing with the sewage, the excessive flow means a quicker filling of the beds, consequently some additional provision in the form of storm beds is necessary for times of excessive rainfall. With regard to this subject, however, it must be remembered that the increased flow due to storm water does not mean any increase of sewage to be dealt with, or an overtaxing of the bacterial action, so that, provided that in the case of tanks the flow through them is not of sufficient rapidity to disturb the general action, no harm need be anticipated, and that in the case of bacteria beds, the sewage being so much more dilute, a shorter period of contact in the bed will suffice.

A simple and effective way of dealing with excessive storm water, of course, is to provide a quick-acting overflow weir. This may be adopted by private parties where there are no restrictions as to the amount which installations shall deal with before overflow takes place. Such overflow, however, cannot of course be treated merely as storm water, and care should be taken that no nuisance is caused by it.

Another point which requires some consideration is the action of frost. Curiously, no great or long-continued frost has occurred since biological installations have been put up, so that it is rather difficult to say what might result in the case of prolonged periods of very cold weather. It can only be supposed that no worse things could happen with these installations than have occurred with sewage works and farms, although doubtless the freezing up of works representing a concentrated purifying action would be more serious than in the case of a farm where latitude exists in some form or other to meet the vagaries of the season. It may be said, however, that as the temperature of sewage is in cold weather always several degrees above that of the atmosphere, it is less likely to freeze than otherwise would be the case. The general question, however, has received some attention, and in the case of the Scott-Moncrieff and Ducat's systems, at least, provision has been made to meet the conditions by the complete enclosure of the filters, and even by the provision of means for warming the plentiful supply of air necessary for proper aeration.

I shall now make some remarks more or less of a general nature. First of all, we may as well call to mind what the micro-organisms engaged really are. The general idea is that they are vicious little animals. They are, however, organisms related to the vegetable fungi, not, as is popularly supposed, of an animal nature. Sewage teems with them. As Professor Bottomley was pointing out the other day in a popular lecture, a cubic centimeter contains 4 or 5 millions, or as many as the population of London, in a thimble.

A very interesting point to note is the way in which the colonies of organisms increase in numbers, and therefore efficiency, according to the work required of them. This increase may be detected by the sense of smell, as it will be found that at the outset a biological installation will prove very offensive, and that as the use of it goes on it will become less and less so, till practically no smell will be perceptible, showing that the apparatus has got into full working condition, or become "ripe," as it is called.

Speaking generally, the micro-organisms concerned in the breaking down and purification of sewage are those which under favourable circumstances produce inoffensive gases. In these circumstances the action is known as a healthy fermentation; should the conditions, however, not be favourable, the decomposition is of a different kind, other gases of an offensive nature are produced, and the fermentation becomes an unhealthy one.

The gases given off in the first stage of the process are carbonic acid, marsh gas, and hydrogen, all of them without odour. In the case of open beds, the gases pass off into the air, but in covered tanks they accumulate, except so far as they may be able to escape through the structure of the tanks, or joints in the manhole covers.

Mr. Martin, Engineer of the Septic Tank Syndicate, states that the calorific value of the gases is equal to between one-half and two-thirds that of coal gas. In some cases it may be burned under an incandescent mantle to light the works, or even used in a gas engine.

A sort of empirical rule has been established, that a liquefying tank should be of about one day's maximum sewage capacity. It has been found that this affords, as a rule, a sufficient length of stay in the tank for the sewage to become liquefied. It is not, however, so certain that the stay of sewage in the tank could be too long. As Mr. Martin puts it, purely theoretical considerations point to the possibility of a tank being too large for its work, and in dealing with certain classes of manufacturing refuse it is desirable that the stay should not be too long. With ordinary sewage, however, it does not appear that there is any appreciable effect. We cannot trace any benefit when the stay is lengthened beyond a certain point, but, on the other hand, there does not appear to be any falling off in the results.

It would therefore seem, in view of what has been said as to the effect of storm water, and the desirability of restricting the rapidity of passage of the sewage through the tank, that the tank should be in excess of requirements rather than below.

In the case of bacteria beds it has been mentioned that there is a rule of one day's sewage capacity. When estimating this, however, allowance has of course to be made for the material in the bed, and for a diminution of capacity, due to the formation of certain residual products during the working of the bed. Experience shows that bacteria beds frequently, owing to this cause, from having a capacity of 50 per cent. of the gross dimensions of the bed, are reduced to from 25 to 30 per cent.

As regards the capacity of filters on the raining down or spraying system, it used to be reckoned that not more than 200 gallons per square yard, at the most, equal to about 1,000,000 per acre per diem, should be dealt with. Such filters, however, as those of Mr. Stoddart, as has been pointed out, deal efficiently with very much larger quantities of sewage, even up to 1,000 to 1,200 gallons per yard, if of a depth of 6 feet. The depth of filters, it has been generally considered, should be not less than 4 feet to 5 feet, but in the case of bacteria beds, where the available fall is not great, good work has been done with beds of a much less depth, and as regards filters it will be remembered that a filter on Mr. Stoddart's principle may be at least only 3 feet in depth, and still give excellent results.

It does not appear that as regards tanks there is any advantage in filling them with stones or other material, as in Mr. Scott-Moncrieff's principle, but that an ordinary tank brings about liquefaction just as well.

Bacteria beds of the primary kind may be filled with almost any kind of large rough material, such as stones, flints, burnt ballast, etc., but as regards the matrix for the secondary beds, experience shows that while many different materials may be used, they should be of fine grain. As regards continuous filters, it used also to be considered that the material of these filters should also be of a somewhat fine grain; but later experience, and especially that of Mr. Stoddart, would seem to show that the larger material secures more complete aeration.

It will be recollected that when mentioning chemical precipitation in connection with works for sewage farms the large amount of sludge, and the getting rid of it, presented very serious difficulties. An important point in connection with the biological process is that, by the adoption of it, sludge may be looked upon as a practically negligible quantity. The hydrolytic action which takes place removes practically all that part of sewage which constitutes sludge. There is, however, a slight fine residue which deserves some special notice. This is in no sense a sludge, but consists of a humus-like deposit, containing some nitrogen. In character it closely resembles pond mud. It is very stable, and resists chemical action. It is generally considered to be indissoluble, but it would appear that as it is capable of supporting plant life it must slowly disintegrate. The amount of it is comparatively small; in the case of tanks it forms as a layer on the bottom, and it is for the purpose of providing for this deposit that tanks are made, as a rule, not less than 6 feet deep. In the case of the first septic tank installation at Exeter, which has been about 6 years at work, the deposit has only just been removed, having a quantity equal to about half the depth of the tank in depth. Provision, however, is, and always should be, made for running it off or for pumping it out from the bottom.

No deposit of this humus-like nature takes place in contact beds, as might be expected from the methods adopted for running in and running off the sewage, whereby doubtless the humus is carried away, but a certain quantity of it would appear to attach itself to the matrix in the beds, and it is probably partly due to this that the capacity of the beds is reduced, as previously mentioned.

In connection with all installations it is necessary to provide some means for intercepting road detritus and other similar inorganic matter, which comes down the sewers, and therefore what are known as grit pits are provided. These in their simplest form were merely oblong brick pits, with bottoms some few feet below the inlet and outlet drains. It was found, however, that these arrested organic matter as well, which should of course pass on to the tanks or bed. I have lately, therefore, constructed pits of the form shown in *Fig.* 11, *Plate* VIII., where the pit at a level somewhat above and below the line of the drains is kept very little wider than the diameter of the drain, so that the lighter organic matter is carried onwards by a direct current to the outlet, while the heavier inorganic matter sinks to the bottom.

The Septic Tank Syndicate have adopted the idea in a modified form, and construct their grit pits with curved and hinged iron plates (see *Fig.* 12, *Plate* VIII.). These plates effect the desired object of directing the lighter matter to the outlets, and can be raised to enable the detritus in the bottom of the pits to be removed.

The pits used in connection with "contact" beds must be of a different nature, as they must not only arrest the inorganic matter, but also the larger organic portions of the sewage. These arrangements consist of a small pit with some mechanical means for removing the organic solids, or of larger pits with strainers. A representation of the latter is given on *Fig.* 13, *Plate* IX.

A word of warning must be given to those considering what system to adopt. The success which has attended the provision of many rough adaptations of the process has often encouraged the supposition that almost any arrangement will suffice so long as it conforms to general principles, no matter what is the nature of the sewage to be dealt with, and has led to consequent disappointment.

The question of what system should be used cannot be answered merely by considering the physical conditions to be dealt with, but involves very often an enquiry as to the constituents of the sewage. The results of experiments and of permanent installations are so varied, and apparently so contradictory, that the explanation could only be in the difference of the quality of the sewage. In the case of domestic sewage pure and simple it would seem that little more than the physical circumstances need be calculated for, but in any case it is desirable that recourse should be had to the advice of experts in the chemistry and biology of sewage, in order that the effect of certain constituents of the sewage may be allowed for, and arrangements made accordingly. Installations show that while in one case filtration gives the best results, in another place, as at Manchester, the septic tank and double contact beds are the most successful.

To lend itself to proper bacterial action sewage should be neither acid nor alkaline. If any departure from this rule is made it should be on the side of alkalinity, but not to any great extent. In the case of some towns the sewage is rendered so acid from manufacturing effluents that special arrangements are made to add lime to it to obtain the desired neutrality.

Apart from trade effluents, sewage sometimes contains preponderating elements which require very special treatment; to cite instances very near home, the sewage from some of the recently erected hutments for cavalry and artillery has proved very intractable. In these cases the latrines are on the dry earth principle, so that the sewage consists of slop water, laundry water, and urine, and a very large proportion of stable drainage containing much hippuric acid. The result has been that no healthy anaerobic action takes place, and, consequently, to apply the sewage in the second stage to oxidizing filters is at present futile. The sewage in these cases is being applied in its raw state to land of a porous nature, which fortunately adjoins each site.

It is hoped that when the latrines are supplied with the water system the preponderating influence of unsuitable sewage will be overcome, and that the sewage will be of such a character that proper bacterial treatment will result.

In cases in which much laundry water enters the sewers allowance must be made for the soapy element which is introduced. It is broken down by the bacterial action similar to that of sewage generally, but the process is slower; consequently a longer duration of the liquefying stage is necessary, and the tanks must be made larger in proportion to the amount of soapy water introduced. There are other elements doubtless which, in special cases, affect the ferment in a similar way, but the above have been mentioned as examples of matters requiring special treatment.

You will be interested to learn how far the War Department has availed itself of the developments which have taken place in the purification of sewage by biolysis, and I am happy to be able to say that rather than being behind in availing itself of the knowledge to hand, it has been well to the fore in putting it in practice.

In doing this it has been its endeavour, while taking advantage of the system generally, to afford opportunities for the trial of the installations best known. When the subject was practically in its infancy the sewage of Worcester Barracks was giving great trouble, and legal proceedings were threatened on account of the pollution of a stream; an opportunity therefore occurred for applying the principles. This was done as follows:—Some existing covered sewage tanks had their tops removed, the interiors were cleaned out and filled with coke, and over the top, branching from a main channel, a number of trays were placed one foot apart. A septic tank was constructed on the line of the main drain leading to these tanks, and from the septic tank the sewage was led to the filter beds, formed as described.

This installation did not represent exactly any of those which had been constructed at that date, but it appeared to be on right lines, and the results were entirely satisfactory, as the stream was no longer polluted, and the effluent as analysed by the professor of hygiene proved to be satisfactory. A similar tank and filter were shortly afterwards constructed to deal with the sewage of Glencorse Barracks with similar results (see *Plate* IV.).

At a later date, on the question of the disposal of the sewage of Tipperary Barracks cropping up, on account of the pollution of the adjacent river, a complete Septic Tank Syndicate's installation was adopted, and has been at work with satisfactory results for the last three years. At a later time the sewage of Caterham Barracks was dealt with by the provision of a Scott-Moncrieff installation, and in this case also the results have been satisfactory, the effluent being purified to a degree unheard of previously in connection with biolysis. Within the last two years double contact beds have been installed at the Curragh Camp in Ireland, to take the whole of the sewage from that place (see *Plate* III.). It is perhaps early to mention results, as no final report on them has been given, but inasmuch as they have now been working some months, and without complaint, it is probable that the results are satisfactory. In one or two other cases further installations by the Septic Tank Syndicate have been provided, to wit, at Devizes Barracks and the Okehampton Camp. Arrangements have also been made to deal with the whole of the sewage of the new barracks at Tidworth, on Salisbury Plain, on this principle. In Mauritius, in connection with barracks where the latrines are on the dry earth principle, and only slop water is to be dealt with, a Colonel Ducat's filter is about to be provided.

No opportunity at present has occurred for putting up an installation on Mr. Stoddart's principle, but it is hoped that should such occur, advantage of his methods will be taken.

It will also be interesting to recall the progress which the system has made generally. In the early days, when the results of the first experiments became known, they were looked upon generally by engineers and chemists with a good deal of scepticism, not to say ridicule. The results of the practical application of the system, however, to more or less large quantities of sewage tend to prove the results previously arrived at, and it began to be recognized that this system could not be ignored, and therefore the question was taken up by many scientific men who had become interested in the matter. A large number, however, and among these engineers and chemists of considerable repute, some of whom, however, shortly afterwards posed as experts, still looked upon the matter as visionary and of no practical value. The enormous cost of procuring the land required for sewage farming, and considered by the Local Government Board to be necessary for treating sewage, led the authorities of certain towns to inquire into the suitability of the process for dealing with sewage on very large scales, and, as has already been mentioned, under certain conditions the City of Exeter was allowed to provide an installation to deal with the sewage of the whole town. After this, many smaller communities adopted the principle ; then came the notable enquiry, resulting in the experiments made at Manchester, which led to the adoption of a process for that town. Leeds, and other very big places, took up the matter, previously carrying out important experiments, with a view to show what special arrangements, if any, were necessary for the peculiar sewage of their towns.

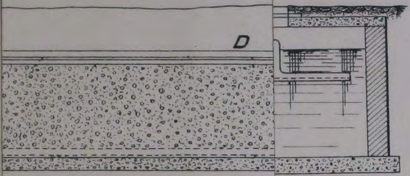
Matters reached this stage, when the Government were urged to reconsider the necessity for adhering to their rules with regard to the provision of land, as a final treatment of the sewage in any circumstances, seeing that it resulted in considerable hardship owing to the cost of the same. The result has been, as you are doubtless well aware, the appointment of a Royal Commission to enquire into the system generally. This Commission has now been at its labours for two or three years, but last year they issued an interim report, one of the paragraphs in which runs as follows:—

"After carefully considering the whole of the evidence, together with the results of our own work, we are satisfied that it is practical to produce by artificial processes alone, either from sewage or from certain mixtures of sewage and trade refuse, effluents which will not putrefy, which would be classed as good, according to chemical standard, and which may be discharged into a stream without creating a nuisance. We think, therefore, that there are cases in which the Local Government Board would be justified in modifying, with proper safeguard, the present rule as regards the application of sewage to the land."

After such an expression of opinion, it would appear that no further advocacy of the system need be made, and I think that this is so. But with regard to the use of land in connection with a biological system of sewage purification, I would point out that although there can be no doubt that a well-devised process is capable of producing an effluent which may not only produce no ill-effects in a watercourse, but may even prove capable, as has been the case, of purifying it, it is desirable, where at all possible, that some adequate portion of land should be available in case of emergency. The biological process is a concentrated one, and as, in the case of all concentrated action, accidents are much farther reaching in their effects than would otherwise be the case, it is best to have a sufficient safety valve in case of emergency. For this reason it is desirable to provide a way to escape from temporary adverse circumstances in the form of a portion of land on which the effluent may be turned. It is to be borne in mind, however, that when considering what available area is necessary, it is not a question of how much sewage will be dealt with, so that purification by nitrifying action in the soil may take place, but how much liquid the ground will absorb. In this latter case, of course, a very much greater amount of liquid may be dealt with, or, to put it the other way, a comparatively small area of land is required.

PLATE I.

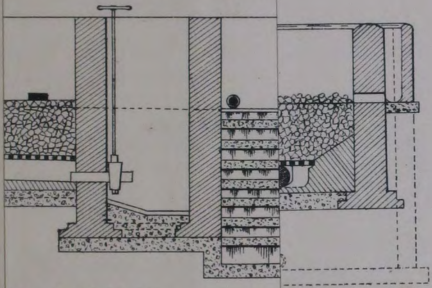
SEPTIC T



IDINAL SECTION. SECTION.

Fig. III.

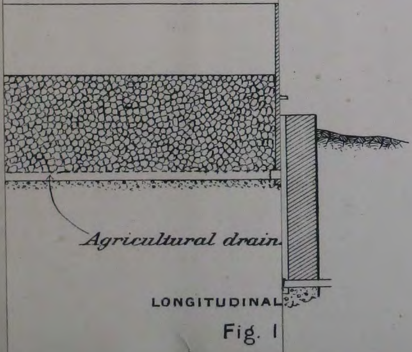
SCOTT-MONC



DINAL SECTION. SECTION.

Fig. I.

DIBDE



LONGITUDINAL

Fig. I

PAPER II.

GRAPHIC SOLUTION OF ENGINEERING PROBLEMS.

BY COLONEL J. H. C. HARRISON (LATE), R.E.

IN the two lectures I had the honour of delivering here last session I explained the outlines of a graphic method applicable generally to the solution of problems in civil engineering, both when the structures are framed or solid, and when they span, or do not span, an interval. I propose in this lecture to take up the subject at the point where we left it, and pass at once to the consideration of a class of structures, the stability and stiffness of which, while admitting of treatment by Rankine's General Theorem, yet demand special attention. These structures are known as fixed and continuous beams.

By a "fixed beam" is meant "a supported beam whose extremities are so fixed that the neutral surface retains its direction at the ends under transverse load," and by a "continuous beam," a single beam, covering several spans and resting on several supports. Now, by supposing the neutral surface extended at both ends a distance equal to the span, and this hypothetical span so loaded as to render the neutral surface horizontal at the section, or sections, of support, that is of fixation, the beam fixed at both ends may be regarded as equivalent to a middle span of a continuous beam; and in a similar way, one fixed at one end and supported at the other may be reduced to the equivalent of an end span of a continuous beam, whose extremity is freely supported. It will be sufficient, therefore, in this lecture to confine ourselves to an examination of the stability and stiffness of beams freely supported at both extremities, and continuous over and loaded between intermediate supports.

In my first lecture I explained how the bending moment area of a discontinuous beam freely supported at its extremities, and loaded in any way whatever, may be drawn in; that of the middle span of a continuous beam, similarly loaded between supports, is drawn in on exactly the same principles; but some portion of the bending effect represented by the former area is employed in the case of the continuous beam in influencing contiguous spans, and the question I shall endeavour to answer this evening is—in what way, and to what extent?

The advantage of the continuous beam consists in the saving of material due to this comparative decrease in the resulting bending effect, and so consequently in the direct stresses; but it is when the spans are long and the permanent load, in consequence, the principal part of the whole weight that this advantage is appreciably felt.

It is remarkable that in England and India continuous bridges may be almost said to be conspicuous by their absence, whereas in France and Southern Germany—where, perhaps, the question of economy of material is a more serious consideration than it is in this country—there are many examples of them. There is, indeed, an illustration close at hand in the L.C. & D. Railway bridge over the Medway at Rochester, but it is a curious specimen of a girder designed as though for a single span, yet continuous over two intermediate supports, and quite worthless for instructional purposes, except to illustrate defects.

In the present lecture I have numbered the figures continuously from those of previous lecture.

In *Fig.* 24 I have shown, in elevation, the outline of a continuous beam $A_1A_2A_3A_4$, which is freely supported at its extremities A_1 and A_4, and continuous over two intermediate supports A_2 and A_3, each span being supposed loaded between the supports. The form of the neutral surface, or rather *line* (being shown in elevation) of this beam (*Fig.* 26*a*), may be said to be a matter of observation, but if its state of strain be compared with that of the three discontinuous beams A_1A_2, A_2A_3, and A_3A_4, shown in *Fig.* 25, which are freely supported at their extremities and loaded similarly to the corresponding spans of the continuous beam, it will be seen that the *visible* effect of continuity is to throw the figure of the neutral line into a sinuous curve, which is convex upwards over the middle supports, and convex downwards near the sections of maximum bending moment of the corresponding discontinuous beam. The portions of contrary flexure join at points of inflexion y_1, x_2, y_2, and x_3 (*Fig.* 26*a* to 27), of which there are in each end span one, and each middle span two.

Thus, each end span is, between the point of free support at the beam's extremity and the nearest inflexion point, as A_1y_1 or x_3A_4 of *Figs.* 26*a* and 26*b*, in the condition of a discontinuous beam freely supported at its extremities and loaded in the interim; the portion of each middle span between the two points of inflexion, as x_2y_2 of *Figs.* 26*a* and 26*b*, in that of a discontinuous beam supported at each extremity on a cantilever and loaded in the interim; and each intermediate segment, as $y_1A_2x_2$ and $y_2A_3x_3$, lying on a middle support and terminated by an inflexion point, in the condition of a double cantilever loaded at each extremity and supported in the interim. The hypothetical load at each such extremity would be measured by the actual shearing force acting there, of which I shall have something to say later on.

The *mechanical* effect of the continuity is to cause the loads on the several spans to produce influences on the supports, causing a re-distribution of the bending force as compared with the corresponding discontinuous beam, and a consequent change in the bending moment curve, which curve will now be found to show a maximum downward moment between each support, and a maximum upward one over each middle support—the result of this being, as already pointed out, to produce a reduction in the value of the maximum moment and of the deflection, as also of the longitudinal stress intensity, and consequently of the material required for the continuous, as compared with that required for the discontinuous, beam. And herein lies the great advantage of this form of beam.

Now, were the material of the beam perfectly rigid, the measurement of the pressures, or reactions, at the several supports, and of the bending moments acting thereat, would be strictly indeterminate, because the equations of equilibrium (viz.: (1), sum of reactions = sum of loads, and (2) moments of reactions about any axis = moments of loads about same axis) only amount to two in number, and the bridge is, by hypothesis, supported on more than two points. But in the case of elastic material, the properties of which are fully known, this determination becomes a perfectly definite problem, depending for its solution on Hooke's law of elasticity, *ut tensio sic vis*, or *strain varies as stress*, whence is deduced the relation on which the general equation of the elastic or deflection curve is based.

Time forbids my dealing in detail with this relation, but I must, at least, crave your patience while I just run through the steps in the formation of the equation to the deflection curve, because the determination of the moments over supports, as well as of the deflection, of a continuous beam, both depend on its employment.

If ρ be put for the radius of curvature of a loaded beam's neutral surface, or rather neutral *line* (being seen in elevation), I for the moments of inertia of any chosen cross-section about that surface, $\pm$M for the bending moment at that cross-section, and E for the modulus of elasticity of the material of the beam, that is, for the purely imaginary weight in pounds (av.), which, if hung at the end of a strip of the material of 1 square inch cross-section, would elongate it by its own length, then it is easy to show that

$$\frac{1}{\rho} = \pm \frac{\mathrm{M}}{\mathrm{EI}} \qquad \text{.............................(1).}$$

Substituting for ρ the well-known differential expression, we have for the differential equation to the elastic curve

$$\frac{d^2y}{dx^2} = \pm \frac{\mathrm{M}}{\mathrm{EI}} \qquad \text{.........................(2),}$$

in which for beams of uniform section throughout their length I is constant; whence, by integration, we obtain the general equation to the elastic or deflection curve,

$$y = \pm \frac{1}{\mathrm{EI}} \iint \mathrm{M}dx^2 \pm x \times (\text{constant}) \pm (\text{constant}) \qquad \text{......(3).}$$

It is thus seen, as pointed out in a previous lecture, that before the form of the elastic curve can be known, that of the curve of bending moments must be determined, and that in order to trace the former, the latter must be *twice* integrated. Moreover, if I be regarded as constant, the *form* of the beam will be that of a girder with parallel flanges, as shown in *Fig.* 24.

It might be inferred, perhaps, that the bending moment in passing from a maximum upward value at the points of support (other than the extremities of the beam) to a maximum downward value at some point, or rather section, between them passes at the points of inflexion through value zero, and an examination of the equation to the elastic curve (equation (3)) will show that such is indeed the case. For a necessary condition in order that a curve may cut its tangent, that is, that a point of inflexion may occur, is—as many of you no doubt know—that the value of $\frac{d^2y}{dx^2}$ shall at that point vanish. Now this can only occur in equation (3), provided $M = O$ at the section in question.

I desire particularly to point out that whereas the stability of a *discontinuous* beam, freely supported at and loaded between its extremities, is, as I have shown in a previous lecture, readily determinable by graphic methods, that of a *continuous* beam, supported at its extremities, and supported and loaded intermediately, is not so, because the law under which the bending force is distributed is not at once apparent. Were the positions of the points of inflexion known, obviously the curve of resultant bending moments could be at once drawn in, because, as will be seen later on, the moment curve of the upward as well as of the downward influences must pass through these points. Their positions, however, depend on the loading, and must consequently change as the latter changes. By severing the continuity of the girder by means of a pin or hinge placed near the positions of inflexion points, the latter become mechanically fixed, and we obtain the form of girder known as the cantilever type, of which the Forth Bridge, shown in outline in *Fig.* 42, is a notable example. This form of girder cannot be strictly said to be continuous, although its neutral surface, when subjected to transverse load, assumes the same form as that of the strictly continuous beam shown in *Fig.* 24. I shall hope, however, before finishing this lecture, to be able to show how the moment curve of this latter type may, with perfect ease, be graphically determined—a problem which, by analytic methods, is but partially and with difficulty soluble.

There are, then, two determinations to be made—one a question of strength, viz., the moment area; the other a question of stiffness, viz., the deflection curve. They are distinct and different, although both are arrived at on similar principles.

We shall first examine the stability of the middle portion of the beam, shown in *Fig.* 27, lying between the points of inflexion, that is, of zero moment, y_1 and x_3, and including the portions outside the supports A_2 and A_3, because the equilibrated system of the three parallel loads S_1, W_2, and S_3, balanced on the points A_2 and A_3 lying between them, shown in *Fig.* 27, may be regarded as kindred to that obtaining in the middle span of a continuous beam, the loads S_1 and S_3 corresponding to the influences exercised on that span by loads borne on contiguous spans, and will at least indicate the form of the moment area of the latter system. Having ascertained the *form* of this area, we can then neglect the overhanging portions and confine our attention to the portion of the beam lying between the supports only.

The case may be dealt with by considering the system of the two loads S_1 and S_3 lying beyond the supports separately from that of the single load W_2 lying between them, and then *superposing* the diagrams so obtained the one on the other. The resultant reaction at each support will then be the sum of those obtained in each case. For convenience of reference I have coloured in all cases areas of upward moment red, and those of downward moment blue.

Figs. 28*a* and 28*b* show respectively the moment polygon and stress diagram obtained in the usual way for the single load W_2, hung from the weightless beam y_1x_3 of *Fig.* 27, which is freely supported at the points A_2 and A_3, the moment area being entirely downward, and therefore coloured blue; *Figs.* 29*a* and 29*b*, those of the same beam similarly supported but loaded at its extremities with the weights S_1 and S_2, the moment area being entirely upward and red; while *Figs.* 30*a* and 30*b* show those of these two cases superposed—that is, these figures exhibit the equilibrium polygon and stress diagram of the weightless beam y_1x_3 of *Fig.* 27, loaded with a single load at each extremity and also intermediately between the supports, the resultant area being partly upward and partly downward, *i.e.*, partly red and partly blue; and it will be observed that the conditions of this combined case only differ from those obtaining in the middle span of a continuous beam in that the magnitude and position of each of the loads S_1 and S_3, hung externally to the span A_2A_3, and corresponding to the influences of contiguous spans, are supposed known. If, then, while ignoring the actual magnitudes and positions of these overhanging loads, we still suppose their influences on the supports A_2 and A_3 to remain the same, we shall reduce the conditions very nearly to those obtaining in the middle span of a continuous beam.

We conclude, then, that the moment area of the middle span of a continuous beam may be regarded as made up of two moment areas, superposed the one on the other—one, a certain upward area in the form of a trapezium, which, by joining two of its opposite angles, may be converted into two triangles ; the other, a certain downward area, the form of which is either triangular, polygonal, or curved, according to the loading, and is exactly the same as that of a similar discontinuous beam, freely supported at its extremities and similarly loaded between its supports ; further, that the difference of these areas lying above the line drawn through the inflexion points measures the portion of the resultant area representing the influence on contiguous spans, that is, the moments over supports, this area, moreover, representing an upward, or red, influence.

Before going further, I would remark that the terms *upward* and *downward* in this connection are *purely conventional*, and simply mean that the momental influences of contiguous spans on the span in question are contrary to that of the downward loads or weights placed thereon ; further, that it is generally necessary to consider the moving load apart from the permanent one, because many diagrams have to be drawn for the varied positions of the former, whereas a single set suffices for the latter, so that the several cases of uniform, symmetrical, unsymmetrical, isolated, and zero loading must be provided for. In *Figs.* 31 to 38 I have shown the construction for drawing in the elastic curve of a series of spans quite variously loaded—span A_0A_1 being supposed uniformly loaded throughout, A_1A_2 with a single detached load, A_2A_3 with three detached loads, and A_3A_4 with zero load, *Fig.* 32 showing the corresponding stress diagram.

The first point to consider is how the magnitudes of the moment areas I have referred to are to be measured ; the second, having determined these areas, how the elastic curve is to be traced.

With regard to the first, by assuming the areas known to begin with, and then examining their integrated forms, we shall be enabled to arrive at the key whereby the moments over supports are determined ; and having thus ascertained the bending moment area, the elastic curve may be traced.

As already stated, these areas have to be *twice* integrated. Now, in a previous lecture I have shown that the process of integration is, in fact, a process of summation, and in order to perform the operation, therefore, we may either employ a stress diagram in the manner then explained, or else calculate the area to an assumed base in the ordinary way, and treat each area so calculated as equivalent to a load acting through the centre of gravity of the area in question. The latter method is the one employed by

Professor Mohr, and is the one we shall adopt for the first integration.

If, then, the downward area be reduced to that of an equal triangle with half the span length as base, then will the height of that triangle be the graphical equivalent of the hypothetical downward load, and its line of action pass through the centre of gravity of the original downward moment area.

Similarly, if the two triangles into which the trapezium of upward moments is divided be reduced to the same base, viz., half the span, then will the hypothetical upward forces be represented in magnitude by the bases of those triangles respectively, and the line of action of each pass at one-third the corresponding span distance from the support in question.

On each side of a central support, then (as at A_1, A_2, or A_3, *Figs.* 31 to 38), there will be a hypothetical upward force acting, and these two forces will have a single resultant. In a series of unequal spans variously loaded, such as I have shown in *Fig.* 31, obviously the momental influences of these several hypothetical forces must necessarily be different. It is usual to regard the greater of the two bending moments at a support as *the* influence acting there; whence it follows that the momental triangle on either side has a common base at that support, and consequently that the area of each triangle, that is, the magnitude of each hypothetical upward force, varies as the corresponding span length.

Thus, the conclusion is reached that the resultant line of action of the two component hypothetical forces influencing a support divides the total distance between them, amounting to one-third the sum of the span lengths, in the inverse ratio of those lengths, and this resultant line is thus at once determinable in the manner illustrated in *Fig.* 31. I must, however, ask you particularly to note that *its position, as well as those of its components, is fixed when once the span lengths are known, and is completely independent of the downward loading applied to the beam.*

We shall now pass to the second integration of the moment areas, for the completion of which the lines of action and the magnitudes of both the upward and downward hypothetical forces are known. This integration may be performed and the elastic polygon drawn in with the help of merely a skeleton stress diagram, as follows :—

For the pole distance a length of one-third the span must be taken, as will subsequently appear, and with this distance and the hypothetical downward load, measured, as above explained, by the height of the reduced triangular moment area, the extreme sides of the stress diagram are set off in the usual way (*Fig.* 34), and, as explained in a previous lecture, the intercept of a straight line drawn at any section of the beam across these lines measures the moment of the hypothetical downward force at that section. Therefore A_0a_0 (*Figs.* 34 to 36) measures the moment at support A_0.

Denote the lines of action of the parallel upward forces acting near support A_1 by B, R, and C, as shown in *Figs.* 31, 33 to 38, and 43, and that of the reaction at A_0 by A (*Fig.* 43). I must ask you to note carefully the following detailed construction :—

Assume for illustration any point r_1 on R (*Fig.* 43). Join a_0r_1, cutting line B in b_1; join b_1 to support A_1 and produce to meet line C in c_1; join r_1c_1, cutting a_0A_1 produced in f_1. This point f_1 will be found to be constant for all positions of r_1 on R. Thus, if any other point r be taken, and the above process repeated, then will rc be found to pass through f_1. Further, if any other point a_0 (blue) be taken in line A, and the same process repeated, then will f (blue) be found to fall so that ff_1 is parallel to the other lines of action, A, B, R, and C. This construction is also shown in *Fig.* 36.

This geometrical relation, which constitutes the key to the measurement of the moments influencing the middle supports, admits of analytical proof, but one better adapted to lecture purposes is afforded by projective geometry.

Before proceeding to it, however, I would ask you to note that the triangle brc (*Figs.* 33 and 43) forms the equilibrium polygon of the system of hypothetical upward forces consisting of two components, acting along the lines B and C, and one resultant, acting along line R; also that these straight lines, B, R, and C, are constant for *all* positions of the triangle, and are, in fact, the loci of the respective angles of the triangle lying on them; further, that this triangular area of resultant upward moment, as $b_1r_1c_1$ or $b_2r_2c_2$, shown in *Fig.* 36, is contiguous to the area of downward moment, as $a_1g_1a_2$, so that a point determined in the common side of the former is also a point in the side of the latter.

The theorem requiring proof may be stated in general terms as follows :—

If the three angles of a triangle $b_1r_1c_1$ (*Fig.* 43) *always travel along the three fixed straight lines* B, R, *and* C, *which are parallel to one another, whilst two of its sides,* b_1r_1 *and* b_1c_1, *pivot round the fixed points* a_0 *and* A_1 *respectively, then will the third side,* r_1c_1, *pivot round a fixed point* f_1 *in the same straight line with* a_0A_1.

Proof.—As the parallel lines B, R, and C are fixed, and are the loci of the respective angles of the triangle *brc*, the latter may be regarded as a section of the right prism, of which the former are the edges; and as the side b_1r_1 pivots round a chosen point a_0 in the straight line A, which is parallel to the edges B, R, and C, the plane of the face BR of the prism may be supposed extended so as to include the line A, while A_1 becomes a fixed point in the plane of the face BC. Obviously, a plane containing the straight line A and the point A_1 will intersect face RC in a straight line FF, which is parallel to AA, and to the edges B, R, and C. And if any point a_0 be taken in A as the point around which b_1r_1 is to pivot, the result will be the same as if we were to suppose a plane to contain and revolve round a_0A_1, so that the prism is cut in a series of triangles $b_1r_1c_1$, $b_2r_2c_2$......, whose sides r_1c_1, r_2c_2......, will all intersect in f_1, the point in which a_0A_1 produced meets FF (*Fig.* 43) (Q.E.D.).

It will be seen, then, that the point f_1, corresponding to the intercept A_0a_0 on A, becomes, in fact, a "fixed point" for the point a_0, and the straight line FF a locus of *fixed points* for the line AA. It should be observed, however, that while the positions of the lines A, B, R, and C depend entirely on the respective span lengths, those of a_0 and f_1 depend on the magnitude and position of the downward load on span A_0A_1, and consequently that a position may be found for f_1 *when the load is zero*, that is, for an *unloaded* span, under which circumstances f will fall *on* the span itself, as illustrated in *Fig.* 33. *Fig.* 33, in fact, illustrates the usual method of determining the loci F of *fixed points* in a series of spans—a point r_1 being assumed in R to start with, and the detailed construction I have already drawn attention to carried out first from left to right (as from A_0 to A_4), and then from right to left (as from A_4 to A_0), of the girder. The loci F being thus determined, and an intercept, as A_0a_0 (*Fig.* 35), measured, the *actual fixed points,* as f_1, ϕ_1, f_2, ϕ_2, f'_2, etc., are severally determined, two in each middle span and one in each end span, and intercepts measured from them, and in this way, by joining the fixed points diagonally by lines crossing the several spans, as the lines of action of all the loads, both upward and downward, are known, the deflection polygon, as illustrated in *Fig.* 36, is completed without further reference to the stress diagram, the following two checks being applied, viz. :—

I. The two lines joining the fixed points diagonally across each span must intersect on the resultant lines of action of both the upward and downward hypothetical loads; thus, lines $A_0\phi'_0$ and

$a_0f'_0$ of span A_0A_1 must intersect on load line W_1, lines $f_1\phi'_1$ and $\phi_1f'_1$ of span A_1A_2 on line G, and so on; also $a_0f'_0$ and ϕ'_1f_1, produced, must intersect on line R, and so on.

II. The lines joining the intersections of these cross lines with the lines of the *component* upward loads B and C must pass through the corresponding point of support; thus b_1c_1 must pass through A_1, b_2c_2 through A_2, and so on.

I would now direct your particular attention to the similar triangles $a_1c_1a'_1$ of *Figs.* 34 and 36, the former of which was, by construction, the skeleton stress diagram of the moment area $A_1W_2A_2$ of *Fig.* 31. The pole distance, or height, of each triangle is the same in each case, viz., one-third the span (*i.e.* $\frac{1}{3}l_2$), so that $a_1a'_1$ in each case measures the hypothetical downward load, that is, the area of the downward moment triangle reduced to a base of half the span length ($\frac{1}{2}\ l_2$). Hence, a_1A_1, *Fig.* 36, must measure the hypothetical upward force at c_1 and aa'_1, that at b_2, c_1a being drawn parallel to b_2c_2—measured, that is, on the same scale as w_2W_2, *Fig.* 31, measures the bending moment at w_2.

For the hypothetical forces acting at g_1, *Fig.* 36, are, by hypothesis, represented in magnitude by the sides of the triangle $a_1c_1a'_1$; therefore those at c_1 must be represented by the sides of the triangle $a_1c_1A_1$, and those at b_2 by the sides of $ac_1a'_1$.

Hence the necessity for choosing a pole distance of one-third the span length concerned for the second integration, in determining the moments over supports. Thus are these moments completely determined, and a diagram, such as is shown in *Figs.* 31 and 37, of the maximum upward moments over supports drawn in, and the *resultant* moment areas determined as shown by red and blue colours in those figures.

Before leaving the subject of these moments, I would ask you to note that the momental influences at the supports of *loaded* spans of the loads placed on other spans are invariably *upward*, that is, contrary to that of the applied downward loads, there being two inflexion points in each span; whereas in the case of unloaded spans, as is evident from spans A_2A_3 and A_3A_4 of *Fig.* 39, these influences might be either upward or downward, the deflection polygon passing through the fixed point which is further from the loaded span, and the influences in a series of unloaded spans being alternately upward and downward. This will be better understood when we deal with the shearing force.

The method I have just described for determining the moments over supports may be very much abbreviated by the following extremely simple construction due to Professor Lippich :—

The applied load, or loads, having been reduced to a single dead equivalent, and the triangular moment area described, as $A_1W_2A_2$, *Fig.* 39, set off from the section of application of the equivalent single load, as w_2, the span length on either side, as w_2a_1 and w_2a_2, *Fig.* 39, and join a_1W_2 and a_2W_2, producing to cut verticals through supports in β_2 and β_1 respectively. Then will the lengths $A_1\beta_1$ and $A_2\beta_2$ measure the intercepts at the corresponding supports, and if $A_1\beta_2$ and $A_2\beta_1$ be joined and intersect in G, then will G be a point in the vertical through the centre of figure of the original moment area $A_1W_2A_2$.

If, further, these straight lines A_1G and A_2G cut the corresponding loci of fixed points in f_1 and f'_1 respectively, then will the straight line $f_1f'_1$, produced, cut the intercepts at supports in points a_1 and a_2, such that A_1a_1 measures the moment over support A_1, and A_2a_2 that over A_2.

The proof of this is easy ; but as time does not admit of my giving it I will leave it to you to supply, especially as it is not adapted to lecture purposes.

We are now in a position to proceed to the construction of the elastic curve. For this, as I have already pointed out, *resultant* and not *component* areas must be dealt with, so that the first thing to do is to draw hypothetical load lines through the centres of figure of each of the resultant moment areas already determined and shown in *Fig.* 37. Next, it must be borne in mind that the same bases of reduction must be employed throughout, so that some one span must be selected as the standard, and the intercepts of all the other spans reduced to it as base.

This is most shortly done, when the first of the methods I have described is employed, by reducing the height of the moment triangle to the new base in the manner illustrated in *Fig.* 41, which depends on the equality of the complements of parallelograms, area aa'_3 being equal to area A_2a_3, and then describing a new skeleton stress diagram and elastic polygon in the manner already explained and illustrated by yellow lines in *Figs.* 34, 35, and 38—projecting, in fact, the polygons round A_0A_4.

When Professor Lippich's method is employed the reduction of the intercepts at once may be effected by the construction shown by yellow lines in *Fig.* 34, which depends on a *double* application of the property of parallelograms above referred to. Thus the intercept aa'_2 of span A_2A_3, length l_3 (*Fig.* 34), becomes $a_2a'_2$ when reduced to span length l_2 as base, length βa_3 (yellow) being laid off from a_3 equal to l_2, $a'_2\beta_3$ being drawn parallel to aa_3 and β and β' joined to β_3.

The elastic curve, having been drawn in, the deflection δ at any section may be evaluated by measuring the length y of the ordinate at that section on the lineal scale, and substituting in equation (3), which, as explained in a previous lecture, will now take the form

$$\delta = p \times \frac{l}{2} \times \frac{l}{3} \times \frac{1}{EI} y = \frac{pl^2}{6EI} y \quad \ldots\ldots\ldots\ldots\ldots\ldots (8),$$

p being the pole distance of the first stress diagram (*Fig.* 32) measured on the load scale, and l the length of the standard span.

For the measurement of the shearing force we will examine span A_2A_3 of length l_3. It will be convenient to confine ourselves to *Figs.* 37 and 40, the latter of which shows the stress diagram for span A_2A_3 of *Fig.* 37. The load line is figured *st* (*Fig.* 40), and the lines of force being all numbered, it will be seen, from what I said in my first lecture, that the shearing force or reaction R_2 at A_2 of the corresponding *discontinuous* beam A_2A_3, whose moment area is $a_2W_3W_4W_5a_3$, *Fig.* 37 (compare *Fig.* 40), would be measured by tg, and the shearing force or reaction R_3 at A_3 by gs; further, and for similar reasons, that for the moment area $a_2W_3W_4W_5a_3A_3A_2a_2$ of the span A_2A_3 of the given *continuous* beam the reaction or shearing force S_2 at A_2 is measured by tg', and that at A_3, that is S_3, by $g's$. If M_2 and M_3 denote the moments at the supports A_2 and A_3 respectively, and the distance of each isolated weight from A_3 be denoted generally by the symbol a, and moments tending in the direction of the hands of a watch be considered positive, then we have for the moments about A_3 the following expression, viz. :—

$$S_2 \times l_3 + M_3 - \Sigma(Wa) - M_2 = 0 \quad \ldots\ldots\ldots\ldots\ldots (4).$$

$$\therefore \qquad S_2 = \frac{1}{l_3} \times \Sigma(Wa) + \frac{1}{l_3}(M_2 - M_3) \quad \ldots\ldots\ldots\ldots (5).$$

But $$R_2 = \frac{1}{l_3}\Sigma(Wa) \text{ (by elementary statics).}$$

Hence $$S_2 \text{ (or } tg') = R_2 + \frac{1}{l_3}(M_2 - M_3) = (tg + gg') \ldots\ldots\ldots\ldots (6).$$

So likewise $$S_3 \text{ (or } g's) = R_3 - \frac{1}{l_3}(M_2 - M_3) = (gs - gg') \quad \ldots\ldots\ldots (7).$$

Now in an unloaded segment R_2 and R_3 (*i.e.*, *tg* and *gs*) are absent, and we have

$$S_2 = -S_3 = \frac{1}{l_3}(M_2 \backsim M_3) \dots\dots\dots\dots\dots\dots (8),$$

the shearing force at the supports constituting, in fact, a couple, and balancing the moments produced by the loads on other spans ; these forces must, therefore, act alternately upwards and downwards at the supports, and as their influences or moments must diminish and not increase as we pass further from the loaded segment, the deflection polygon must pass through the fixed point which is *further* from the loaded segment, that is, through a point situated in the third of the span further from the load.

Lastly, it should be noted that, were the continuous or fixed beam symmetrically loaded throughout, we should have a_2a_3 parallel to A_2A_3 in *Fig.* 37, vectors 5 and 6 would correspond in *Fig.* 41, g coinciding with g', and the shearing forces or reactions at the supports would be the same as if the span were discontinuous.

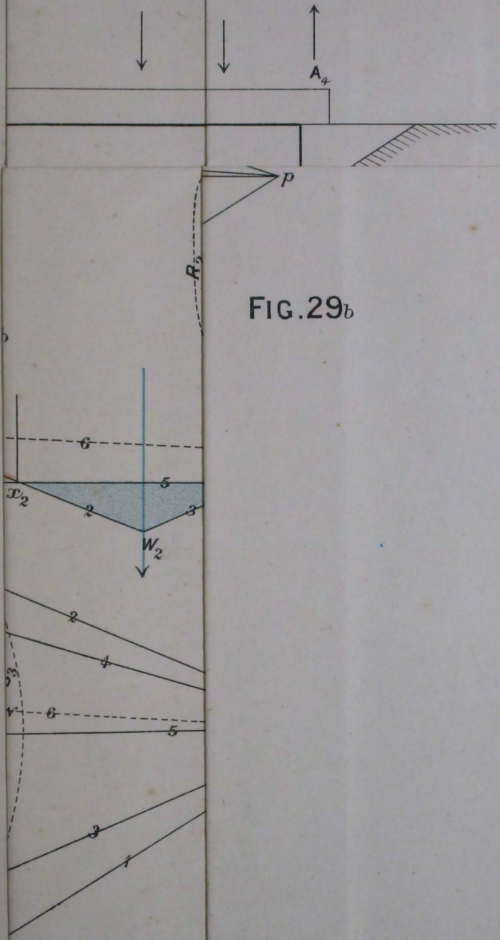


FIG. 29b

PAPER III.

MILITARY BALLOONING IN THE BRITISH ARMY.

By Colonel C. M. Watson, C.B., C.M.G.

The use of Military Balloons in the South African War on a considerable scale may be regarded as marking an epoch in that branch of the duties of the Corps of Royal Engineers, and the present, therefore, appears a suitable time to record briefly the steps by which the existing organization has been arrived at. It has been a slow and gradual process, as forty years have elapsed since the first definite proposal was made to introduce a balloon equipment suitable for reconnoitring purposes.

1862. This proposal was made by Lieut. Grover, R.E. (the late Colonel Grover, who died in 1893), who read a paper upon the subject at Chatham on the 23rd April, 1862, entitled "On the Uses of Balloons in Military Operations." This article, together with two other papers, the first, also by Lieut. Grover, on "Reconnoitring Balloons," and the second by the late Colonel Beaumont, R.E., both of which were read at Chatham on the 14th November, 1862, are printed in the XIIth Volume of the *Royal Engineers Professional Papers* (New Series), and are well worth perusal by those who wish to make a study of the subject. They contain an excellent *résumé* of the history of the use of balloons in war up to the year 1862, and discuss in a clear manner the advantages to be obtained from balloons, and the equipment which it appeared desirable to provide in order to obtain those advantages.

Colonel Grover proposed the employment of a silk balloon 28 feet in diameter, which he calculated would give, with hydrogen gas, a lifting power of 718 lbs., and this he considered would be sufficient, after deducting the weight of the envelope, net, car, and holding-down ropes, to lift two men to the required altitudes. It is interesting to note that the size of balloon he recommended was almost the same as that adopted for the service balloon many years afterwards. As regards the process of manufacturing the hydrogen, Colonel Grover explained the two methods, that with sulphuric acid and zinc, and that in which the gas is evolved by passing steam over red-hot iron turnings or charcoal, and he considered that experiments should be made to ascertain what was the most desirable arrangement of gas-generating apparatus for military service. He concluded his article by pointing out the necessity of reducing the balloon equipment to a practical system, quoting a remark of the late Emperor Napoleon III., that " whatever is complicated fails in producing good results in warfare ; the promoters of systems forget always that the object of progress ought to be to obtain the greatest possible effect with the least possible effort and expense." After the date of Colonel Grover's paper, some experiments were made at Aldershot with one of Mr. Coxwell's balloons, which was hired for the purpose. It was filled with coal gas, and used for reconnoitring up to an altitude of 1,200 feet.

After this but little progress was made for some years. Ascents were occasionally made by officers, and some small experiments were carried out, but the use of military balloons was not taken up seriously by the War Office.

1871. The Franco-German War of 1870–71 brought the question forward again, and the subject was one of those referred to the Royal Engineers Committee, which had been re-constituted in 1870, to consider inventions and improvements in articles of Engineer equipment. The small committee, which had up to that date been dealing with balloon questions at Woolwich, was made a sub-committee of the Royal Engineers Committee. At the time these changes were made, the main points which had been under consideration were

(*a*). The nature of apparatus most suitable for producing hydrogen in the field.

(*b*). The nature of material to be used for the balloon envelope.

1872. As regards the first point, the Committee directed their attention to the construction of an apparatus for producing the gas by passing steam over red-hot iron. In the first experiment a fire-clay gas retort was used, and was charged with broken-up cast-iron shell. A considerable quantity of gas was evolved, but the fire-clay retort proved unsatisfactory, and a further experiment was made with wrought-iron tubes, the broken-up shell being replaced by wrought-iron turnings. The result proved much more satisfactory, and it was recommended that a furnace containing eight tubes should be constructed in order to carry out experiments on a larger scale.

As regards the material to be used for the envelope, a series of experiments were made by Professor Abel, the War Department Chemist (now Sir Frederick Abel, Bart., K.C.B.), who gave it as his opinion that, although a linen fabric coated with unvulcanized indiarubber would resist the escape of hydrogen sufficient for practical purposes, more perfect reliance could be placed on silk of high quality, and that the latter would be most durable.

The Royal Engineers Committee finally recommended that the experiments with the red-hot iron process should be continued and that a balloon should be purchased to practice men in observing from a height. The result of the recommendation was, that funds were provided for the erection of the gas furnace, but not for the purchase of a balloon.

1873. The gas furnace was built in Woolwich Dockyard in 1873. It contained eight wrought-iron tubes supplied by Messrs. Russell & Co. The tubes were 7 feet 6 inches long and 5 inches internal diameter, the thickness of metal being half an inch. The ends were fitted with screwed-up mouthpieces which could be removed to insert the charge of wrought-iron turnings. The tubes were set horizontally in a brick furnace. The steam passed from the boiler through a super-heater into the tubes, where the oxygen was taken up by the iron turnings, and the hydrogen was passed into a separator, which cooled the gas and condensed any steam which might have come over. A number of experiments were made, and, in the best of these, 196 cubic feet of hydrogen was obtained per hour from each cwt. of iron turnings. The experiments showed that it was possible to produce hydrogen in large quantities, but that the necessary apparatus would be of great weight. It was calculated that the weight of the furnace, tubes, etc., to produce 14,000 cubic feet of gas in 10 hours would be

20 tons, that the weight of the iron turnings for the charge would be $2\frac{1}{2}$ tons, and of coal for the boiler 5 tons. These weights appeared, for a field apparatus, to be prohibitive.

While these experiments with the steam apparatus were going on, the provision of a field apparatus for making gas by the sulphuric acid process was under consideration. In 1873 it was proposed that a balloon equipment should be sent to the West Coast of Africa for use in the Ashantee Campaign, and the Balloon Sub-Committee was directed to work out the details of an equipment. Negotiations were entered into with Mr. Coxwell, the aeronaut, who agreed to supply a balloon of the best quality of silk, with net, car, etc., for £1,200, or two balloons for £2,000.

As it was clearly out of the question to use the steam and iron process for the production of hydrogen, an apparatus for making gas by sulphuric acid and zinc was worked out in such a manner that each package did not weigh more than 80 lbs. This was necessary, on account of the difficulty of transport on the Gold Coast. It was calculated that the weight of iron turnings and acid, including suitable vessels for holding the latter, would be about 10,000 lbs. for each filling of the balloon. The cost of the equipment was estimated at £2,400 for one balloon. It was finally decided not to send out the equipment, and although this was regretted at the time, it can now be regarded as a satisfactory decision, as the attempt might very probably have proved a failure, which would have prejudiced the authorities at the War Office against the use of balloons in military operations.

The experiments with the furnace for the production
1874. of hydrogen were continued during 1874, but it was not found possible to reduce the weight of the apparatus, and
1875. in a report dated 25th January, 1875, the Sub-Committee on Balloons expressed the opinion that an apparatus for the sulphuric acid process would be far lighter. They also suggested that it would be desirable that the hydrogen for use with military balloons should be carried in steel cylinders, so that the gas could be generated at any convenient locality, and carried to the point where the balloon was to be used. The Committee recommended that the cylinders should be 6 feet in length, with an external diameter of 14 inches, and a thickness of $\frac{3}{8}$ inch. The gas to be compressed to a pressure of 1,000 lbs. to the square inch. The weight of cylinders, which would contain 14,000 cubic feet of hydrogen, was calculated at 5 tons 6 cwt. This was a very important proposal,

which, although not worked out at the time it was made, led to successful results some years afterwards.

The Committee further recommended that experiments should be made with hot-air balloons, which they considered might under certain circumstances be employed with advantage. These experiments were carried out, but did not lead to any satisfactory results.

1878. During the succeeding three years but little progress was made, and the chances of obtaining a military balloon equipment appeared small, but in 1878 a fresh start was made under more hopeful conditions. Capt. Templer, of the King's Royal Rifles Militia, an officer who had devoted much time to the study of ballooning, and who was a skilful aeronaut, was present at Woolwich Arsenal during some experiments, and it was suggested to him (I believe by Sir F. Abel) that he should place his services at the disposal of the War Office, to assist in the preparation of an equipment. He agreed to do so, and a sum of £150 was allotted to enable him to build a small balloon. A design was made for an envelope to contain about 10,000 cubic feet of hydrogen, that being considered a suitable size. The material adopted by Capt. Templer was cambric, coated with a varnish which he had found to be very effective in retaining the gas. The balloon was completed in August, 1878, and was named the "Pioneer." It was sent to Woolwich Arsenal for trial, and was filled for the first time on the 23rd August. The cost of the balloon was £71, which compared favourably with the sum of £1,200, suggested by Mr. Coxwell in 1873 as the price of a balloon to be supplied for military service in Ashanti.

While the "Pioneer" was being built, Capt. Templer took up the improvement of the apparatus for the production of hydrogen. He erected a new furnace, containing two retorts, and succeeded in obtaining 8,000 cubic feet of gas in 10 hours. Capt. Templer also commenced the instruction of some officers of the Royal Engineers in the management of a balloon, and took them for free ascents in his private balloon, the "Crusader." It was arranged that he should receive remuneration at the rate of 10s. per diem for the days he was actually employed. The War Office decided to continue experiments with balloons, while not as yet accepting them definitely as a recognized part of the Engineer equipment of the army; and a small amount was granted for the purpose. It must be recognized that a very important advance was made in 1878, and it is interesting to note that it had taken sixteen years to arrive at this stage, since 1862, the date of Colonel Grover's original propôsal.

Experimental work was continued at Woolwich during
1879-81. the next three years, so far as the limited sums placed at the disposal of the Balloon Committee would allow. In 1882, when the British Expedition was sent to Egypt, a proposal was made to supply the army with a balloon equipment, and
1882. a commencement was made in providing the necessary apparatus. But the war came to a conclusion before anything was definitely settled, and this opportunity of trying balloons under particularly favourable conditions was lost. This was much to be regretted, as Egypt, from the nature of the country and the atmospheric conditions, was admirably adapted for the use of balloons. Had there been a balloon with Sir Gerald Graham's force at Kassassin, the whole of the fortifications at Tel-el-Kebir could have been thoroughly reconnoitred, and the advanced eight-gun redoubt, in front of the right section of the Egyptian lines, would not have escaped observation. As regards this point, it is worth quoting from the official history of the campaign:—"The powerful eight-gun advanced work, which lies in front of the Egyptian right, had been twice seen, once by Lieut.-Colonel Tulloch from near the canal, and once by Colonel Buller from the hill south of the canal, but on neither occasion had it been possible to distinguish it from the main body of the work, and from the front it could not be seen, being altogether below the crest of the hill." The work was about 1,200 yards in front of the general line of fortification, and was less than six miles from the British camp at Kassassin, while the hill that concealed it was about a mile in front of it and not more than 15 or 20 feet above it. The fact that its existence was unknown might have had a very serious effect on the British night attack, as the left flank of General Sir E. Hamley's division passed it at a distance of about 1,200 yards, while quite unconscious of its existence. When dawn broke, and as the Highland Brigade were attacking the lines, the guns of the advanced work opened fire on the division and on the headquarter staff, and artillery had to be brought up to silence it. If the left flank of the division had extended a little further to the south, it would have struck the advanced work, which would have opened fire and alarmed the Egyptian Army in the lines of Tel-el-Kebir while the British force was still at a considerable distance. Had this occurred the losses would undoubtedly have been far heavier than they were. If, however, there had been a balloon at Kassassin, the work would have been thoroughly known, and this great risk would not have been incurred.

In October, 1882, it was decided to transfer the experiments at Woolwich to Chatham and to carry on future work at the School of Military Engineering under the Royal Engineer Committee, and to detail a small number of officers and men of the Royal Engineers to be trained in military ballooning. This may be regarded as the first step that was taken in the direction of the formation of a balloon section. The points which were taken up were:—

(*a*). Further investigations as to the apparatus and materials for the production of hydrogen gas and the method of filling balloons in the field.

(*b*). Consideration of the fabric to be adopted for the balloon envelope.

(*c*). The best method of attaching the car to the net of the balloon.

(*d*). Training the officers and men in observation.

(*e*). Balloon photography and signalling.

With regard to the question of the generation of hydrogen, the steam and red-hot iron process was now definitely abandoned, and an improved apparatus for making gas by means of acid and zinc was devised, which gave satisfactory results. It was found that granulated zinc was better than iron turnings, as it gave a purer gas. The form of apparatus that was adopted remained in use until lately, when it was superseded by an apparatus for producing hydrogen by the electrolysis of water. This will be referred to later.

The question as to the material to be adopted for the envelope of the balloons was one that required great consideration. The cambric material, of which the "Pioneer" had been constructed, though very light, and when well varnished, fairly capable of holding hydrogen, was not sufficiently lasting for military work, and experiments were, therefore, made with silk. A small balloon,

1883. called the "Sapper," of 22 feet diameter and 5,600 cubic feet capacity, was built, and found fairly satisfactory. But this was the only silk balloon constructed, as a new material was introduced by Capt. Templer, which proved far superior to anything that had been experimented with prior to 1883. This was the material usually known as "gold beater's skin," as it had been used for many years in the process of making gold leaf. It is a part of the interior membrane of the gut of an ox, and is very tenacious and practically impervious to the passage of hydrogen gas. In consequence of this latter quality it had long been used for the manufacture of toy balloons and small balloons for scientific purposes.

Capt. Templer, with whom were associated the late Mr. Walter Powell and Lieut. Trollope, of the Grenadier Guards, had formed the idea that if the skin proved so satisfactory for small balloons it should also be the best material for the construction of man-carrying balloons. It was, therefore, decided to make the experiment, and a family of the name of Weinling, who had long been engaged in the manufacture of small balloons, were taken into the employ of Mr. Powell with the view of making a large balloon under the superintendence of Capt. Templer. The construction of a large balloon proved no easy task, and it was found that it was considerably more difficult to build a balloon of 27 feet diameter than one of small size. Mr. Powell was doubtful as to arriving at success, and handed over the balloon to Capt. Templer. The latter placed his invention at the disposal of the War Office, and it was decided to complete the balloon at Chatham. A ball court at St. Mary's Barracks was roofed over and turned into an erecting shop, and the Weinling family were engaged to complete the balloon, which was named the "Heron." It was completed in 1883, and gave such satisfactory results that skin was definitely adopted as the material to be used, and has continued to be so employed ever since.

The manufacture of the net and rigging of the balloon was also thoroughly investigated. It was at first proposed to use silk cord, but this was superseded by Italian hemp, which was specially made for the purpose. Great care was taken in the manufacture of the cord in order to insure that every fibre took its part in bearing the strain.

In June, 1883, Major Lee, R.E., who was in charge of the experiments at Chatham, was sent to Paris with Lieut. Trollope to visit the balloon exhibition in Paris, and they made an interesting report on the progress that had been made in France. Among other inventions, the dirigible balloon of Monsieur Theodore Paston was reported upon. This gentleman used the same material for the envelope of his aerostat (gold beater's skin) as that which was being tried at Chatham, but the French authorities were, as a rule, in favour of silk on account of the difficulty experienced in making balloons of the skin.

A very important question was now taken up, which was as to the best method of carrying hydrogen in the field. A compressor was purchased by the Royal Engineers Committee, and experiments were made in compressing the gas into steel tubes. One of the difficulties was the provision of a suitable valve which could be easily worked, and not be liable to get out of order, and which would at the same time hold the gas perfectly. A new valve was devised to meet the necessary conditions.

1884. By the beginning of 1884 the whole of the details of a field equipment had been worked out to a very considerable extent, and it was therefore possible, as soon as funds were provided, to make a complete equipment. In April of that year it was suggested that a Balloon Corps should be sent to Egypt for use in the Sudan Campaign, then in contemplation, and instructions were given by the War Office to complete the details of a small equipment. A considerable number of steel tubes, to hold hydrogen, and compressing pumps were provided, and the construction of some additional balloons of gold beater's skin was also proceeded with. A small number of non-commissioned officers and sappers were detailed to be trained as a balloon detachment.

But the detachment was never sent up the Nile, as, before orders were received for it to start, a new development took place. The aggressive spirit shown by the Boers in the Western Transvaal led to an expeditionary force being sent under General Sir Charles Warren to Bechuanaland in the autumn of 1884, and it was decided that a balloon equipment should be sent with the British force. Major Elsdale, R.E., who had succeeded Major Lee at Chatham, was in command of the detachment, which comprised Lieut. Trollope, of the Grenadier Guards, and 10 N.C.O.'s and sappers. The detachment embarked for Cape Town on the 25th November, 1884, and proceeded at once to Mafeking. The equipment included three balloons, *i.e.*, the "Heron," the original 10,000-cubic-foot skin balloon already referred to, the "Spy," a 7,000-foot skin balloon, and the "Feo," a skin balloon of 4,500 cubic feet capacity. Two smaller balloons, each of 370-foot capacity, were also taken; 27,000 cubic feet of hydrogen was taken out, compressed in steel tubes. The tubes proved very satisfactory. The gas was made at Chatham and stored at a pressure of 2,100 lbs. on the square inch, and after the sea voyage and rough journey up country not one of the 150 tubes, nor of the valves, showed any symptom of leakage.

Operations were commenced on the 6th April, 1885, when the "Heron" was filled at Mafeking. Owing to the dryness of the air, the balloon developed some cracks, but these were repaired without difficulty. The "Spy" was filled on the 8th April, and proved to be a very good balloon. The "Feo" was filled later, and, notwithstanding its small size, took up one man, although the country at Mafeking is 5,000 feet above sea level. Considering the nature of the equipment, the experiment was satisfactory, but it was shown that the detachment of 10 men was too small for the effective working of the equipment.

1885. Early in 1885, after the news of the fall of Khartoum and the death of General Gordon was received, an expeditionary force was sent to Suakin, under the command of General Sir Gerald Graham, and orders were sent to Chatham to send a balloon detachment with the force. This was rather a serious demand, as the best part of the balloon equipment had already been sent to South Africa, but everything possible was done to prepare a second equipment, and the detachment embarked on the 15th February, 1885. Major Templer was in command, and had with him Lieut. Mackenzie, R.E., and 8 non-commissioned officers and sappers. The equipment consisted of three balloons, *i.e.*, the "Scout," of 7,000 cubic feet, the "Fly," of 5,000 cubic feet, and the "Sapper," of 5,600 cubic feet capacity; 22,000 cubic feet of hydrogen was taken, compressed in 120 tubes, and a small gas works with pumps for compressing the gas was also provided. Search lights and a signalling apparatus also found part of the equipment. The balloons were filled on several occasions, and, on the whole, worked satisfactorily, but the arrangement for transport left much to be desired, and, as in the case of the Bechuanaland Expedition, the strength of the detachment was too small for the work. It may be worth while, as regards this, quoting some remarks of Colonel Edwards, C.R.E. at Suakin. He said:—

"On the 25th March, when the balloon was able to accompany the convoy, the men derived the greatest confidence from it, as they knew they could not be surprised, and the convoy itself could move much faster and more freely, only making occasional halts to close up. The subject, however, is of such vast importance that it is hoped that the experience gained in this campaign may be utilized and the science still further developed, when it cannot fail to be of the greatest advantage to an army in the field, especially when operating in a broken country, or when covered with thick bush, like the neighbourhood of Suakin. The detachment employed was numerically too weak for the duty, and it is absolutely necessary that the men should be thoroughly drilled and instructed in handling the balloon in a moderate breeze. On the 2nd April we were obliged to supplement the detachment with men from the Royal Engineer companies, who had never worked a balloon before, consequently they were quite unable to keep it steady."

The balloon detachments returned from South Africa and Suakin in the summer of 1885. During their absence Lieut. Macdonald, R.E., was in charge of the depôt at Chatham, and pressed on the provision of additional equipment and the manufacture of hydrogen to keep up the supply in the field.

The results of the experience gained in the two expeditions showed that the balloon equipment was based on satisfactory lines, but needed improvement in certain particulars. The skin material for the envelopes had held the hydrogen well, but required to be made stronger. The steel tubes for containing the hydrogen had proved beyond question the great advantage of using them instead of the old system of making gas when required for an ascent. These tubes were 8 feet in length, 5 inches in internal diameter, and weighed 75 lbs. each. The capacity was 1¼ cubic feet, so that with a pressure of 1,500 lbs. on the square inch, each tube contained 120 cubic feet of gas. The tubes were designed by Major Templer, in conjunction with Lieut. Trollope and Lieut. Macdonald, and were manufactured by Messrs. Delmard, of Birmingham.

It was conclusively proved that the strength of the detachments was insufficient, and that at least 30 men should be provided to work a balloon satisfactorily.

After the return of the balloon detachments from the two campaigns, the manufacture of balloon equipment was proceeded with. Two new skin balloons of 10,000 cubic feet capacity, and two of 7,000 cubic feet, were made in the following year, and the provision of waggons, specially fitted for working a field balloon, and for carrying the gas tubes, was taken in hand.

Experiments were made with balloon photography, more especially with automatic cameras lifted by small balloons of 1,000 cubic feet and 370 cubic feet capacity. The object was to take photographs of an enemy's position without having to send up a man-carrying balloon. The results were fairly satisfactory, but it appeared, on the whole, that it was more important, in the first instance, to complete the field equipment.

1886. In September, 1886, the Balloon Detachment was sent to the artillery practice ground at Lydd, to carry out experiments in observing the effects of artillery fire, and also to see what effect artillery fire would have on a balloon, and how near to an enemy's position a balloon could be worked with safety. After the experiment had been completed, the Ordnance Select Committee reported strongly in favour of the use of balloons for observation purposes, especially in siege operations; both on the side of the attack and defence. The experiments as regards the injury which could be done to a balloon by artillery fire were inconclusive, but, so far as they went, were in favour of the balloon, as the guns could not injure it when at a distance of 3,100 yards.

Although the small establishment at St. Mary's Barracks, Chatham, enabled the manufacture of the equipment to be proceeded with, it was found that it was in many respects not suitable as a place for training the men, being too much surrounded with buildings. To meet the difficulty, Major Templer took some ground, at his own expense, at Lidsing, about five miles from Chatham. This was an extremely good situation, as it was on the hills, and well suited for training the men in observation. It was quiet, and at the same time within easy distance of the gas depôt at Chatham. The land was hired by the War Office from Captain Templer for two or three seasons, and a balloon camp established during the summer months. This proved a satisfactory arrangement, and great progress was made in the technical training of the balloon detachment. As there was no balloon shed at Lidsing, a pit was dug in the chalk of sufficient depth to take a 10,000-cubic-foot balloon, which was thus kept completely secured from the wind. This is a device which might be very useful in the case of siege operations, or on such other occasions when it may be necessary to keep a balloon for some time in one place, as the chance of loss of gas is, of course, much less than when the balloon is tied down in the open.

1887. It was decided, in the beginning of 1887, to make a definite appointment of Instructor in Ballooning with a salary of £600 per annum, and Major Templer was gazetted to the post on the 1st April. This was the first acknowledgment in the Army Estimates that balloons formed a part of the equipment of the British Army. It was satisfactory that Major Templer was appointed, considering how much was due to his energy and knowledge in the provision of the balloon equipment, and that he had given his services for nine years to the War Office for a very small remuneration.

In the summer of 1887 training was carried on in the Balloon Camp at Lidsing, and in August a detachment was sent to the Artillery Range at Lydd, for further experiments. During the winter of the same year the manufacture of additional balloons and the fitting of the waggons was proceeded with.

1888. In April, 1888, Major Elsdale left Chatham, and I succeeded him in charge of the Balloon Establishment. At that time the strength of the Establishment was as follows :—

1 officer in charge.
1 instructor in ballooning.

Balloon Detachment.

1 lieutenant.
1 serjeant.
15 rank and file.

Balloon Factory.

1 military mechanist.
1 civilian gas maker.
1 ,, storeman.
1 ,, driver.
10 balloon-making hands.

The manufacture of balloons was proceeding satisfactorily, and the most pressing work was the completion of the equipment waggons. They were finished shortly, and were inspected by the Royal Engineers Committee on the 8th June. The train consisted of the following :—

1 balloon waggon with hauling-down gear.
3 tube waggons, each carrying 44 tubes.
1 equipment waggon with spare balloons and stores.
1 water cart.

As the balloon detachment was not provided with horses, the waggons were horsed by one of the field companies. The waggons were paraded again on the 21st June, for examination by the Inspector-General of Fortifications. A few days later the balloon detachment proceeded to their summer camp at Lidsing, and remained there until the end of September. In August a part of the detachment was sent to Lydd to continue the experiments in the observation of artillery fire. A balloon was also fired at, but very little damage was done to it. The range was about 3,600 yards, at which distance no injury was effected which would have stopped the balloon from working.

As has been already observed, it had been shown by experience that Chatham was not a suitable place for the Balloon Depôt. The space allotted to it was far too cramped, and the ground in the vicinity was not suitable for training. Major Templer proposed that the War Office should take over his land at Lidsing, and that a Balloon Factory and Depôt should be provided there. There was no doubt it was admirably adapted for the purpose. The authorities at the War Office, however, did not concur in the proposal, but agreed to hire the land for another season for the training of the detachment.

The Balloon Camp at Lidsing was formed at the end of
1889. May. As the detachment was still unprovided with horses, the waggons were fitted with draw bars, so that the whole train could be drawn by a traction engine. The arrangement was found to be a very convenient one, and after this a traction engine was generally employed for the movement of the balloon equipment.

In June the detachment was sent to Aldershot to take part in the summer manœuvres, and was favourably reported upon by General Sir Evelyn Wood, who was impressed with the great value of them in war, and expressed the opinion that they were likely to play an important part in the campaigns of the future. He concluded by recommending that the Balloon Establishment should be moved from Chatham to Aldershot, as the latter was a more suitable place for training the balloon officers in the observation of movement of troops.

The supply of gas for the balloons during the manœuvres was kept up from the depôt at Chatham, the waggons being drawn by traction engines in the manner already described. 130,000 cubic feet of hydrogen was forwarded to the detachment while at and near Aldershot.

In September, 1889, I was ordered to the War Office, and Major Templer took over the duties of officer in charge of balloons, in addition to his work as Instructor. The detachment remained under the command of Lieut. Ward, R.E.

This year was a very important one in the progress of
1890. Military Ballooning in England. In the Army Estimates for 1890–91 a Balloon Section was authorized as a permanent unit of the Corps of Royal Engineers, with a strength of—

3 officers,
3 sergeants,
28 rank and file,

and in addition a military mechanist and an engineer clerk were authorized for the factory and depôt. This may be regarded as the termination of the experimental stage, and the recognition of balloons as a necessary adjunct of the army. In the same year also another important step in advance was taken. Up to that time the Balloon Factory had been in St. Mary's Barracks at Chatham, but the buildings were small and unsuitable, and the requirements had far outrun the accommodation that was available. It was, therefore, decided to provide a factory on a proper scale, at an estimated cost of £9,000. The most pressing need was for a balloon erecting shop, as the old ball court, which has already been alluded to, was too small, and could only contain a single balloon. This naturally hampered progress in a very serious manner. To begin the work a sum of £1,000 was voted in the Army Estimates for 1890–91. Before any commencement was made, the important question as to the best site for the factory received very careful consideration. The position of the temporary factory at Chatham was certainly not satisfactory. Aldershot presented many advantages, and had been recommended by the general officer commanding at that station. There was also Lidsing, at the farm which Major Templer had taken, which would have been very suitable. The authorities at the War Office finally decided in favour of Aldershot, and a site was selected for the factory in the South Camp in the Royal Engineer Lines. The position had the advantage of being close to the barracks, where the section would be quartered, and also of being near to the Basingstoke Canal, from which water could be obtained for the purposes of the factory. But it had the disadvantage that it was surrounded by buildings, and took up ground which, sooner or later, was certain to be required for the extension of the Engineer buildings. The matter having been decided, the transfer of certain of the sheds and machinery from Chatham was at once commenced, and a contract was made for the erection of a shed for the manufacture of balloons. The framework of the building was of iron and the casing of wood. Besides the balloon shed, buildings for the gas factory and compressing pumps, workshops, tube stores, general equipment stores, waggon sheds, were also provided. In each of the succeeding years a small sum was voted for the building of the factory, which has, in consequence, taken ten years to complete, at a total cost of about £15,000.

The erection of the factory placed the manufacture of the equipment on an entirely new basis, as a largely increased number of hands could be employed in building balloons, while the quality of the work was greatly improved. Several very important changes were made in the next few years in the mode of manufacture, but these are details into which it is not necessary to enter. It is sufficient to say that balloons can now be produced at a rate that will meet all present requirements.

Up to the time of transfer from Chatham three classes of balloons had been in use, namely, the T class, or balloon of 10,000 cubic feet capacity, the S class of 7,000 cubic feet, and the F class of 4,500 or 5,000 cubic feet. During the last few years two new classes have been introduced for use in exceptional circumstances. These are the A class of 13,000 cubic feet, and the V class of 11,500 cubic feet capacity. Steady improvement has also been made in the nets, rigging, valves, and other accessories of the balloons, and though, of course, there can be no finality in such matters, the equipment of the balloons can now be regarded as very efficient.

Progress has also been made in the provision of tubes to carry the compressed hydrogen. The tubes originally provided prior to the Bechuanaland and Suakin Expeditions have already been described. These were 5 inches in diameter, and contained 120 cubic feet of compressed gas. But the weight was considerable in proportion to the amount of gas carried. In 1893 a new pattern of tube was introduced, the capacity of which was 3 cubic feet, so that they held 300 cubic feet of gas at a pressure of 100 atmospheres, and the weight of steel was about 1lb. for each three feet of gas. But these tubes did not prove very satisfactory, as the limit of safety was too low. After careful experiments, another type of tube has been adopted, which have given good results. These are manufactured by the Mannesman Tube Company, at Landore, in South Wales. The tubes are 9 feet long, 8 inches interior diameter, and hold 500 cubic feet of hydrogen at a pressure of 120 atmospheres. These tubes have a valve at both ends, instead of at one end only, which considerably facilitates the operation of filling, and has other advantages.

I have already alluded to the numerous experiments which were carried out from time to time with reference to ascertaining the best method of manufacturing hydrogen for balloon purposes. Prior to 1882 the red-hot iron and steam process had been most in favour, but when the move to Chatham took place in that year, it was given up in favour of the zinc and acid process, and the latter has remained in use until the present year. There are grave objections to the acid process, and it has been felt for many years that some better system should be adopted. The cost of manufacture is very considerable, and sulphuric acid is a very undesirable material to have in the balloon works. A little acid passes over from the generators with the gas, and although the greater part of this acid is expelled by the process of compression, there is a risk of some passing over and injuring the skin of the balloon envelope. The method of manufacture which was theoretically the best was to separate the hydrogen from water by the system of electrolysis, and the adoption of this system was considered as far back as 1880. Small experiments were made from time to time. In 1882 a trial was made at the works of the Anglo-Brush Electrical Company, but it was found that the gas contained some of the sulphuric acid with which the water to be electrolyzed was acidulated. Further experiments were made in the Electrical School at Chatham in 1888, but without satisfactory results.

When the Balloon Factory was moved from Chatham to Aldershot in 1890, there was so much work to be done in other directions that the subject of electrolysis remained dormant until 1893, all the hydrogen required being made by the zinc and acid process. In that year a proposal was made by the Superintendent of the Balloon Factory that a plant for the production of gas by electrolysis should be provided at an estimated cost of £2,500. The question was referred to the Royal Engineers Committee, who recommended that, before taking the step of adopting the electrolytic process, experiments should be made with an improved apparatus for the manufacture of hydrogen by the zinc and acid process. The question was under the consideration of the Committee until the end of 1896, and numerous experiments were made, with the final result that the Committee recommended the purchase of a small electrolytic plant for trial. After a series of experiments with it, it was so evident that it was superior to the zinc and acid system that it was finally decided to purchase a full-sized plant from Messrs. Siemens. This plant has now been installed in the Balloon Factory, and gives very satisfactory results. It is on a scale sufficient, when working at full power, to produce 10,000 cubic feet of hydrogen in 24 hours. The cost of manufacture is estimated at 6s. 6d. per 1,000 cubic feet, as opposed to 40s. per 1,000 cubic feet, the actual mean cost of the gas made by the acid process.

In 1897 an important change was made as regards the **1897.** organization of the Balloon Factory. Up to that time Lieut.-Col. Templer had held the appointment of Instructor in Ballooning, as well as being the officer in charge of the factory. But it was now recognized that the latter had become of sufficient importance to make it the sole charge of an officer, and Lieut.-Col. Templer was appointed Superintendent, while the instructional duties were entrusted to the officer commanding the Balloon Section. The latter officer was under the command of the officer commanding troops and companies at Aldershot, while the Superintendent was placed directly under the orders of the Inspector-General of Fortifications.

In the autumn of 1899, when preparations were being **1899.** made for the South African Expedition, it was decided to send out a balloon equipment with the army. At that time the organization consisted of one section only, no augmentation having been made since 1890, but as the force being embarked for service in South Africa was large, and as the balloons were likely to be wanted in more than one part of the country, the section was at once expanded into two, the stock of balloons and other equipment in store enabling this to be done without difficulty.

The 2nd Section, with Capt. H. B. Jones in command, embarked on the 30th September, 1899, and the 1st Section, under Capt. G. M. Heath, embarked on the 4th November. The latter section was sent on to Natal and got into Ladysmith before the siege commenced, but the whole of the balloon stores did not arrive by the time the Boers had cut the communications. The 2nd Section was sent to the left flank of the English advance, and was attached to General Lord Methuen's division. During the advance of Sir Redvers Buller's force and the relief of Ladysmith, the want of a balloon was much felt, and a detachment was organized under Capt. Phillips, R.E., who made use of some of the stores of the 1st Section, which had been left in Pietermaritzburg. This detachment did very useful work during the operations on the Tugela. It was never regularly constituted as a balloon section, and was not continued after the relief of Ladysmith.

As it is well to know the views of our adversaries respecting the use of balloons in South Africa, I will quote some of the remarks of Colonel Lynch, who served with the Boers, and who recently gave a lecture in Paris on the use of balloons in war. He observed that the balloons were of great utility to the British troops at various places, but especially at Ladysmith, Colenso, the Modder River, and Fourteen Streams, and went on to remark as follows :—" As all the world knows, in warfare with smokeless powder it is very difficult to determine the actual position of a battery or of a body of infantry which attacks suddenly. But the observations made by the help of a balloon often permitted the English to note exactly the position of a battery, of a laager, or of military works. Therefore the Boers took a dislike to the balloons. All the other instruments of war were at their command. They had pieces of artillery, superior for the most part, and better served than those of the English; they had all the telegraphic and signalling apparatus; but the balloons were a symbol of superiority on the side of the English which seriously disquieted them. Very often they directed their fire on the balloons, and generally it was entirely wasted. Sometimes, it is true, they hit the balloon, and it even happened that they made it descend rapidly, but above a certain altitude the balloon was generally found to be untouchable.

" The indirect service which the balloons rendered to the British was also very important; that is to say, they were so well informed about the Boer positions that they could divine the object of a combined movement, and it was, thanks to their dispositions, in consequence of this information that they repulsed the attack of Platrand, or Cerai's Camp, a mountain which overlooked the town.

" The balloon again rendered great service at Fourteen Streams, where it remained in activity the whole time with only one inflation. The balloon was a mark for the bullets and shrapnel of the Boers, who had reason for being hostile to the aerostat, for the observation it permitted gave the necessary information to the English to enable them to frustrate the combinations of the enemy.

" To sum up my observations, I believe that the balloon is of the greatest value in military operations, above all in sieges, and in that instance as much to the besieged as the besieger."

Although a good supply of compressed hydrogen was sent out with each section, it was considered desirable to equip a small gas factory for each. The factory for the 1st Section was forwarded to Natal, and that for the 2nd Section was erected at Cape Town.

In December, 1899, Colonel Templer was ordered to South Africa in command of the steam-road transport train, and Lieut.-Colonel Macdonald, R.E., was appointed Acting Superintendent of the Balloon Factory at Aldershot.

1900. Early in 1900 it was decided to send out a third Balloon Section to South Africa, and its organization was at once proceeded with. It was placed under the command of Lieut. Blakeney, R.E., who was given the local rank of Major. The section embarked on the 7th March, and arrived at Cape Town on the 30th, whence it proceeded towards Kimberley, and took part in the operations near Warrenton. Prior to this, the 1st Section had been of great use in the defence of Ladysmith, and the 2nd Section had done excellent work in the advance on Bloemfontein, especially at Paardeberg.

To show the growth of the Balloon Corps, it may be interesting to compare the provision in the Army Estimates for 1900–01 with that in 1899—1900. In the latter year there was one section, with 3 officers and 31 N.C.O.'s and men. In 1900–01 the corps was composed of 3 sections, with a strength of 8 officers, 173 N.C.O.'s and men, with 36 horses.

In the summer of 1900 a fourth section was raised for service in China, and embarked, under the command of Lieut.-Colonel Macdonald, on the 11th August. A very complete equipment was sent out with the section, but the balloons were not much used in consequence of the early termination of the campaign.

On Lieut.-Colonel Macdonald proceeding to China in command of the 4th Balloon Section, his place as Acting Superintendent of the Balloon Factory was taken by Major Trollope, who, as has already been mentioned, had been frequently employed in former years in connection with the balloon service.

1901. In the summer of 1901 the balloons were no longer considered to be required, having regard to the nature of the military operations in South Africa, and the officers and men of the section were employed on other duties. The 1st Section became the 3rd Field Troop, Royal Engineers, the 2nd Section became the 2nd Field Troop, while the 3rd Section was transferred to the railway department.

Early in 1901 Colonel Templer returned from South Africa and resumed charge of the factory. The experience gained in South Africa had shown very clearly the great advantage to be gained by the use of balloons in military operations. The War Office fully recognized the necessity of increasing the strength of the Balloon Corps, and in the Army Estimates for 1901–2 provision was made for a depôt and five sections, to which the cadre of a sixth section has been added in the present year. The additional sections are now in course of formation.

Military ballooning in England may now be regarded as on a fairly satisfactory footing, and the progress made has been considerable, although the expenditure incurred has been very small compared with the amounts given for the service in other countries, such as France and Germany. But, of course, further improvements can be made in various directions, and every year will doubtless show some step in advance. The question of dirigible balloons has to be taken up, as it will never do for England to be left behind in the path of progress. But there is no reason why, if funds can be allotted for the purpose, the Balloon Factory at Aldershot should not produce a dirigible balloon as good, if not better, than that which can be made in any factory on the Continent.

To conclude this short historical account of the progress made in Military Ballooning in England, it may be desirable to recapitulate the more important dates which have already been referred to.

1862.—Lieut. Grover's proposal for the establishment of a Balloon Corps.

1878.—Construction of the first military balloon.

1882.—Balloon Factory commenced at Chatham.

1883.—Introduction of the use of skin for the balloon envelope.

1884–5.—Balloons used in South Africa and in the Sudan.

1887.—Instructor in Ballooning appointed.

1890.—Provision of the 1st Balloon Section and establishment of the Balloon Factory at Aldershot.

1897.—Superintendent of Balloon Factory appointed.

1899—1900.—Three Balloon Sections sent to South Africa and one section sent to China.

1902.—Establishment of Balloon Corps raised to six sections.

PAPER IV.

THE ERECTION OF BRIDGES.

(*Lecture Delivered by* F. E. COOPER, ESQ., M.INST.C.E., *at the School of Military Engineering, in February,* 1902).

THE subject Bridge Erection (various), upon which I have the honour of addressing you, is of great interest to engineers, and especially at the present day to gentlemen of your profession, who during the last 30 years have had so often to deal with it under very exceptional circumstances.

It will be my endeavour to present it to you in as concise a manner as possible; this is a necessity, as the time allotted is too short to permit of its treatment with any great detail.

In designing a bridge the conditions of the problem governing economy in its construction, and suitability for the purpose desired when the structure is complete, are to a great extent simple, and not difficult to determine; but the question of its erection, as regards its safety during the process, the time occupied, and the cost, is in many cases, and especially so far as large structures are concerned, usually somewhat complex.

I propose to consider the subject under the following general heads :—

I.—Pile bridges.

II.—Masonry bridges.

III.—Metal bridges of spans up to 60 feet.

IV.—Metal bridges of larger dimensions erected on staging supported from beneath.

V.—Metal bridges of large spans lifted bodily into position.

VI.—Metal bridges of large spans rolled or floated into position.

VII.—Metal bridges of large spans erected by overhang, portion by portion, without support from the ground beneath.

I.—Pile Bridges.

In the early times, and in the less civilized countries and elsewhere at the present time, where skilled labour is scarce and the required material plentiful, the form of bridge most generally adopted is that of timber beams resting on timber piles.

The method of construction of such a bridge is simple, and does not call for much detailed description. The usual procedure is to drive piles, say three to five in a row, transversely to the axis of the bridge, each row being distant from that next it the length of the desired span, say 15 to 30 feet, the piling being executed from a barge or raft suitably moored. When the piles forming a row have been driven sufficiently deep to ensure stability they are tied together by horizontal waling, and stiffened by strutting; and when cut off to the correct level the longitudinal beams carrying the flooring are placed upon them by the aid of derricks and tackle worked by winches. A good example of such a structure erected in Glasgow is shown on *Fig.* 1, *Plate* I.

In America and many of our Colonies bridges of large size have been erected of timber; but as a rule the erection of these has been similar in character to that of many of the metal bridges hereafter referred to.

II.—Masonry Bridges.

Practically all masonry bridges have been erected by building the arches composing them upon a temporary platform of timber, carried by timber framework called centering, which is composed of several trusses called centres.

Forth Bridge, Scotland.

Fig. 2, *Plate* I., and *Fig.* 1, *Plate* IV., show the details of the centres used in the construction of the four 57-foot spans of the Forth Bridge, and of similar spans at each end of a viaduct on the North Approach Railway of that bridge. These centres it will be observed are in two portions, upper and lower, for facility of erection and adjustment. The timbers of the lower portion are 12″ × 6″ throughout; the booms of the upper portion are of the same size, but the trussing timbers are 6″ × 6″; the whole was accurately framed together and secured at the joints by steel plates and bolts. These centres were placed about 5 feet apart; and 3-inch lagging supported the granite and other masonry of the arches, placed in position with the aid of steam cranes on the top.

Great Washington Bridge, Harlem River, New York.

Another instance of such work is shown in *Fig.* 3, *Plate* I., and *Fig.* 2, *Plate* IV., which give details of the centres used in the construction of the 60-foot span land arches of the Great Washington Bridge over the Harlem River at New York. The scantling of the timber was generally $10'' \times 10''$, the centres were placed 5 feet 6 inches apart, and the laggings were 4 inches thick. It may be remarked that these centres were not slacked, but allowed to stand until, in course of time, the action of the weather set them free. The masonry was placed in position by derricks and steam hoists very expeditiously ; 700 cubic yards of arch masonry were hoisted 75 to 100 feet, and set in nine days by a single derrick.

London Bridge and Grosvenor Bridge, Chester.

Among the finest examples of centering are those made use of in the erection of London Bridge (*Fig.* 4, *Plate* I.) and of the Grosvenor Bridge, Chester (*Fig.* 5, *Plate* I.) ; the latter has a span of 200 feet.

III.—Metal Bridges of Spans up to 60 Feet.

These generally consist of two longitudinal girders, to which cross girders are attached, and which in turn carry the floor ; in some cases several longitudinal girders are alone made use of, the flooring, either timber, brick arches, or plates, resting directly upon them.

The erection of the members of these bridges is simple, they being generally lifted into place by single pole derricks or shear legs, with the aid of rope chain or wire tackle and winches.

Metropolitan District Railway.

Fig. 6, *Plate* II., shows the lifting into position of a girder 73 feet 8 inches long, 6 feet 6 inches deep, weighing about 16 tons, by means of two derricks, on the Metropolitan District Railway near Sloane Square.

Forth Bridge.

At the Forth Bridge a girder weighing about 7 tons was raised 180 feet and placed in position with the aid of shear legs, wire rope tackle, and a steam winch (*Fig.* 7, *Plate* II.).

IV.—Metal Bridges of Greater Dimensions and Weight Erected on Staging Supported from Beneath.

When the length of the main girders of a metal bridge exceeds 60 feet, the difficulties of transport generally necessitate their being brought to the site in portions of manageable dimensions, and in most cases in their component parts, which are afterwards put together in their ultimate positions; for this a temporary platform supported on a timber staging resting on the ground is, as a rule, made use of. The construction of this staging where the work is situated over water is practically the same as that described in the case of a pile bridge; and when over the land, trestles with solid foundations are substituted for the piles.

Forth Bridge.

Fig. 8, *Plate* II., shows generally the temporary platform and staging used for the erection of the 168-foot spans of the approach viaduct to the Forth Bridge.

On the south side there were seven of these spans over the water and three over the land; on the north side there were five over the land. In these cases the girders, though put together in the proper position on plan, were raised about 100 feet to the ultimate level, as will be described hereafter.

Penfeld Bridge, Brest.

An interesting example of this method of erection is given in the case of the large swing bridge over the Penfeld at Brest. The main girders of this bridge are cantilevers, with arms of unequal length, being 191 feet 8 inches over the water and 93 feet 1 inch over the land. Each half of the bridge was erected independently on its side of the river, and, when completed, swung into position to meet the other half. The form of the temporary staging and platform on which the permanent work was put together, and the travelling gantries employed, are shown on *Fig.* 9, *Plate* II. The cost of this method of erection, including the timber scaffolding, is given at £4,788, which is about 10 per cent. of the cost of the 900 tons of ironwork in the superstructure. The contractors for the work were Messrs. Schneider, of Creusot.

El Kantara Bridge, Constantine, Algeria.

A variation of this mode of erection, where the temporary platform is suspended from above, instead of being supported from beneath, is afforded by the method adopted in the case of the El Kantara Bridge at Constantine, in Algeria (*Fig.* 10, *Plate* II.). This bridge, of the span of 188 feet, is over a gulf no less than 394 feet deep; these circumstances clearly made it impossible to obtain support from below for the platform upon which to put together the cast-iron arch structure, having a span of 188 feet 3 inches, and a rise of 26 feet 3 inches, which consists of five ribs with braced spandrils, the total weight being 414 tons. The providing of the necessary centering for the construction of the cast-iron arch was the principal difficulty of the erection, and one which was especially great in a country offering so few resources; and at the same time the important conditions of facility and rapidity of construction, with economy of material and cost, had to be fulfilled.

The work was executed in the following manner:—The masonry of the abutments having been built up, between them were stretched and adjusted four chain cables of $1\frac{7}{8}$-inch iron; and each end of these was carried over timber trestles of **A** form strengthened with iron, and securely anchored to masses of masonry; suspension rods were attached to the cables and supported cross beams at intervals of about 6 feet 3 inches; upon these beams a light platform was placed and accurately adjusted to the intrados of timber arched ribs, which, when in position, formed the centres for the permanent work. These ribs constructed in convenient lengths were 6 feet 7 inches deep, of **I** Section, the flanges being formed of two planks $9\frac{1}{2}$ inches deep by $3\frac{1}{8}$ inches thick, bolted on each side at the web, which, with diagonals and verticals, connected the flanges. Commencing at the abutments, these ribs were placed in position, length by length, and were wedged up at the centre to relieve the chains of their weight; and upon them was erected staging to carry the travellers by which the erection of the permanent structure was carried out, during which the ribs supplied the required support. When the ironwork was sufficiently bolted up to become self-sustaining, the timber ribs and staging were first removed, followed by the platform and supporting chains, the operations being similar to those of their erection, but reversed. The maximum strain on the chains was $5\frac{1}{2}$ tons per square inch, and upon the timber in the ribs about $5\frac{1}{2}$ cwts.

Great Washington Bridge, Harlem River, New York.

Perhaps the finest example of temporary staging for bridge erection is that made use of in the case of the two 510-foot main spans of the magnificent Washington Bridge at New York, the details of the erection of the masonry spans of which have already been referred to. This bridge carries a roadway 80 feet wide across the deep ravine of the Harlem River, and thus connects two important districts of the city. It consists of two steel arches of 510 feet span, with three granite arches of 60 feet span on each side. The main spans, one over the land and the other over the river, are each composed of six steel ribs segmental in form, 510 feet span and 91 feet rise; each rib is 13 feet deep, and is composed of 34 segments about 15 feet long.

The staging forming the centres upon which the ribs were put together is shown on *Fig.* 11 and *Fig.* 12, *Plate* II.; the former, that for the land span, was composed of 204 hemlock posts 10″ × 10″, varying in height from 10 to 110 feet, arranged in six rows 14 feet apart, braced horizontally and diagonally about every 17 feet by 10″ × 3″ planks; about 1,500,000 cubic feet of timber was used (*Fig.* 3, *Plate* IV.). As the staging was carried across two railways and a road, the posts over them were supported on portions of the permanent structure temporarily made use of. It was necessary during the erection of the ribs to put in some counterbracing struts, as the unequal loading and some settlement caused slight deformation of the staging; but no difficulty was found in securing eventually the accurate form of the ribs. The staging (*Fig.* 12, *Plate* II., and *Fig.* 4, *Plate* IV.) over the river was similar to that just described; but an opening, 100 feet high above water level and diminishing in width from 75 to 35 feet, was left for the passage of the river traffic; there were no other special openings. The posts over the river rested on piles driven into its bed; those over the land on sills laid flat on the ground. No settlement or displacement of any kind occurred in this staging.

The segments forming the ribs were brought either by water or by land to the site; and, after their edges had been planed to accurate form, they were lifted into place by travelling derricks resting on blocking on the staging. They were bolted in turn to those below them, being set to a curve 3 inches higher at the crown than the finished structure, for the purpose of taking up the compression due to the weight of the rib when carrying itself after the removal of the supporting blocking. The erection of each span occupied about 16 weeks. Two hundred men were engaged upon the erection of the structural steelwork, weighing about 6,000 tons, the whole of which was completed in about 7½ months.

V.—Metal Bridges of Large Spans Lifted Bodily into Position.

Forth Bridge.

The steel viaducts, forming on the north and south sides the approaches to the main structure of the Forth Bridge, consist of five continuous girders covering ten spans of 168 feet on the south side and five spans of the same dimensions on the north. The operation of lifting them into position was as follows:—When the steelwork of the seven spans over the water on the south side had been put together, as previously described, the adjacent ends of the continuous girders were bolted together so that they formed practically one structure 1,176 feet long, weighing 1,650 tons.

Two transverse steel girders (*Fig.* 13, *Plate* III.), 24 feet long and 22 inches deep, with flanges, each formed of two $5'' \times 5'' \times \frac{3}{4}''$ L bars, were fixed under the lower booms of the girders, 2 feet apart; equidistant from and parallel to the axis of each pier, between these 16 feet apart and directly beneath each boom, was inserted (plunger downwards) a hydraulic jack 14 inches in diameter, with a stroke of 12 inches; beneath each jack and resting on the masonry of the pier was placed timber hardwood packing, reinforced with steel flitches and faced with a steel plate 1 inch thick. On each side and between the jacks the transverse beams were supported on timber hardwood packing, placed between them and the masonry (*Fig.* 5, *Plate* IV.).

Water at a pressure of 34 cwts. per inch was forced simultaneously into all the jacks, by pumps conveniently placed on the girders. The reaction of jacks on the masonry steadily raised the whole mass, during which the men at the packings between the jacks followed the movement by thrusting in hardwood wedges.

When, after four successive lifts of 3 inches had been made, the plungers of the jacks had completed their stroke, they were then run back, and the packing beneath them was raised and blocked up; the water was then re-admitted, and the operation of lifting continued until the required height of from 4 to 6 feet was attained.

When everything was in order, and no stoppages occurred from bursting of the joints in the pipes or from the cup leathers in the jacks giving way under the heavy pressure, the raising of the girders the height of 4 to 6 feet, regulated by the thickness of the courses, did not usually take more than about 3 hours.

As soon as everything was secure the wood packing at the outer ends of the transverse beams, alternately right and left, was removed, and the masonry built up in its place, which usually took one day; it was then left to set hard for 48 hours; then packing was inserted between it and the beam. When all was firmly wedged up, the packing at the opposite ends of the beams was in turn removed, the weight therefore being now taken by the new masonry and the packing between the jacks. The masonry was then built in the space now clear, and left for 48 hours; the beams were now packed up on the last built masonry, the packing between the jacks removed and masonry built in its place, taking another day or so; when after 48 hours the packing was inserted here everything was ready for another lift.

It will thus be seen that the masonry of the piers was built contemporaneously with the raising of the girders, and no scaffolding was required for their construction.

As the situation of the work is much exposed to wind, the stability of the superstructure was an important question; by the method adopted it will be noticed that during the cycle of operations the support of the girders was successively three packings of timber, two of the same and one of masonry, and finally two of masonry at the ends of the beams.

On account of the necessity of giving the cement mortar (one part cement to two of sand) ample time to get hard enough to take the weight, the operation of lifting was rather slow; usually 9 or 10 days were taken for a lift of 4 to 6 feet, and the work was carried upwards at an average rate of 10 feet per month. Work, however, was usually suspended during the winter months and in very rough weather.

On account of a public road intervening, the girders of the second and third spans were put together upon a staging at a level of about 28 feet higher than that over the water; and, as the ground fell very rapidly, those of the first span on a staging at a still higher level (*Fig.* 6, *Plate* IV.).

When the main portion of the superstructure as raised reached in turn the level of those girders independently erected, the latter were joined to it, and the whole length of 1,680 feet, weighing about 2,000 tons, was raised through the last 15 feet to its final position (*Fig.* 1, *Plate* V.).

The spans on the north side were raised in a similar manner.

Tay Bridge, North British Railway.

The Tay Bridge carries the double lines of the North British Railway across the stormy estuary of the Tay; its length is 10,527 feet, made up of 86 spans, 13 of which have a length of 245 feet, the remainder varying from 70 to 145 feet. The superstructure is independent; and each of the large spans, weighing 514 tons, consists of two main lattice girders, hogbacked in form, 29 feet deep in the centre and 20 feet at the ends, with corrugated decking 16 inches deep attached to the lower booms. The undersides of these spans are 77 feet above high water. The piers carrying them consist each of two wrought cylinders 16½ feet internal diameter; these were sunk down to a solid foundation with the aid of a movable platform 81 feet long and 67 feet wide, supported on and maintained in position by four adjustable tubular legs 6 feet 4 inches in diameter, having feet 12 feet in diameter, which rested on the bed of the estuary, which has a maximum depth of 40 feet at high water. Brickwork and concrete fill these cylinders, which extend up to 8 feet above high water; above this level wrought-iron columns, 15½ feet in diameter, connected at the top, 65 feet high, form the support for the girders.

Though at one time it was proposed to erect these main girders in position on timber staging, the exposed nature of the site and the frequent passage of vessels caused this idea to be abandoned.

The method adopted was to construct the ironwork of the spans on a suitable timber staging, 400 feet long by 100 feet wide, conveniently situated on the shore (*Fig.* 2, *Plate* V.); as each in turn was completed, two large pontoons, 80 feet long and 27 feet wide, were floated under it through openings left in the staging. When the tide rose the pontoons carrying the girders were floated out and towed to the piers (*Fig.* 3, *Plate* V.), and were accurately adjusted between them; as the tide fell the girders were left in position upon the piers at a level of about 18 feet above high water (*Fig.* 4, *Plate* V.).

As the ultimate level was 77 feet above high water, they were lifted 58 feet by hydraulic power; the support at each end of the girders was afforded, independently of the permanent structure, by temporary steel columns carrying cross girders bolted to them, which were shifted as the lifting proceeded (*Fig.* 14, *Plate* III.).

The operations of lifting a span took as a rule 8 days.

Taff Bridge, Barry Rhymney Railway.

The viaduct carrying the Rhymney branch of the Barry Railway across the valley of the Taff is 1,359 feet long. The superstructure consists of brick arches and seven independent girder spans, varying in length from 120 to 188 feet, resting on brick piers, the maximum height of rails above ground being 118 feet.

Five of these girders were put together on staging from 15 to 30 feet above the ground. The two remaining were erected in sections on staging 40 feet high; and, as each section was in turn added, the completed portion was thrust forward on cast steel rollers (*Fig.* 6, *Plate* V.), temporary timber trestles from 60 to 100 feet apart supporting them between the piers; the weight moved was about 700 tons, the tractive force being supplied through block tackles by two steam winches of 5 horse-power each.

All the girders were raised independently, the maximum height being about 100 feet; and the heaviest girder weighed 372 tons. The operations of lifting were carried out as follows:—

When the girders were put together brackets were bolted on each side to the end posts of the lowest girder, and beneath each was placed a hydraulic jack, 18 inches in diameter; water at a pressure of 1,800 lbs. was then admitted into these at one end of the girder, which was thus lifted 12 inches; it was now packed up with wood blocks. The jacks were then run back and steel collars about 12 inches deep placed upon the heads of the rams, ready for another stroke. These operations were repeated alternately at each end of the girder until a height of 4 feet was attained. Brackets were then bolted to the ends of the adjoining girders, and that just operated upon was lowered slightly, so that its brackets rested upon them.

The brickwork of the pier was then built up, and after 48 hours had elapsed the lifting operations were resumed upon each girder, as in turn it became the lowest in position (*Fig.* 5, *Plate* V.). When all the girders were at nearly the same level it was possible, during the 48 hours' delay, to carry on lifting at such points as were not in connection with those piers where the brickwork had not completely set.

VI.—Metal Bridges of Large Spans Rolled or Floated into Position.

Where the conditions are favourable, that is to say, when, on one or both sides of the river or space to be spanned, a site at a convenient level and of sufficient length can be provided in a direct line of the structure, it has often proved economical and advantageous to put together the spans on such a site, and push or pull them over the already constructed piers into their final position. Girders constructed as continuous over two or more spans are best suited for such operations.

Seine Bridge, Orival, France.

The erection of the bridge carrying the Western Railway of France over the Seine at Orival is a good example of this method (*Fig.* 15, *Plate* III.).

This bridge has two side spans of 115 feet 6 inches and four intermediate of 151 feet 10 inches. The girders are of the continuous lattice pattern, 930 feet 3 inches long and 13 feet 6 inches deep, their undersides being 35 feet above the water, which has a mean depth of 12 feet. The piers and abutments consist each of two cast-iron columns 11 feet 10 inches in diameter filled with concrete.

The approach embankments having been formed to the desired level, a platform of sufficient length for the construction of half the total length was laid down on the right bank, upon which the girders for this portion were then put together; a beak 36 feet long was temporarily attached to the forward end, which portion was also further stiffened by timber struts to minimize the strain arising from absence of support during launching.

Upon the abutments and piers were placed cast-iron rollers 2 feet 9 inches in diameter, and the same also upon the platform on the embankment at points beneath the lower booms corresponding to the distance between the piers.

A powerful winch, worked by 16 men, hauled by means of suitable tackle the completed portion of the structure into place on the left side of the bridge. This operation took 3 days, and the movement was at the rate of $3\frac{1}{2}$ inches per minute, or 16 feet 6 inches per hour.

The construction of the remaining half of the girders was then proceeded with, and in due course they were hauled into position. The superstructure was then blocked up at the abutments and each pier and, when the rollers were removed and the permanent bed-plates inserted, was lowered upon the latter. The construction of the girders, weighing in all about 1,200 tons, and the completion of the superstructure occupied about 9 months.

Ganges Bridge, Cawnpore, India.

A wrought-iron girder bridge, of twenty-five clear spans of 100 feet each, was erected over the Ganges at Cawnpore in a similar manner. On one bank of the river the girders, each 110 feet long and 10 feet 8 inches deep, were put together in pairs; rollers 18 inches in diameter mounted on hydraulic jacks were then placed beneath the lower booms at intervals of 110 feet; similar rollers were placed on the abutments and piers; the spindles of the rollers, in sets of five on each side, were connected by worm gearing, and motion to the forward set only was given by a handwheel worked by 10 men. The hydraulic jacks having lifted the girders, the rotation of the pulleys slowly moved forward the structure, the rate of progress being about 8 feet per minute. The first two spans were thus traversed across the river, and then the next two were proceeded with, and so on until the whole twenty-five were in place. It was noticed that when the overhang was 100 feet the drop at the end was 10 inches, the girders having been temporarily strongly trussed with timber.

Hooghly Bridge, Hooghly, India.

A combination of the rolling into position and floating methods was adopted for the side spans of the Hooghly Jubilee Bridge; this carries the double lines of the East Indian Railway across the river Hooghly at Hooghly, where that river is about 1,200 feet wide, and has a depth near one side of 66 feet at low water, which is increased by floods to 86 feet, the velocity of the current then rising from $4\frac{1}{2}$ to 6 miles per hour.

The superstructure consists of three spans of hogbacked girders; that in the centre is a double cantilever 360 feet long and 52 feet deep, resting on two piers 66 feet long and 25 feet wide, and 120 feet 6 inches apart centre to centre; the side span girders are 420 feet long, one end of the girders of each span resting on an arm of the cantilever, the other end on a masonry abutment (*Fig.* 16, *Plate* III.).

The piers supporting the double cantilever were constructed in about 30 feet of water by means of a caisson, placed and kept in position during sinking to a depth of about 70 feet by two large pontoons. When completed to the requisite level a staging was constructed upon them, and the superstructure above, for a length of 120 feet, was erected thereon; the overhanging portions were then put in place by derricks and similar appliances without further support.

As the river is so deep and has such swift currents, coupled with the fact that the vessels using it are generally of unwieldy proportions and little under the control of the native crews, there being also passenger and merchandise steamers and flats of considerable tonnage, the use of fixed staging was considered inadmissible for the erection of the side spans; the execution of these was carried out as follows :—

Upon the viaducts forming the approaches to the bridge solid ways of four 60-lb. rails laid close together on a solid timber foundation were constructed, extending about 450 feet from the abutment and in the centre line of each main girder. The girders were then put together upon timber supports laid on the ways. When this work was complete, at the ends of the girders next the abutments hardwood cross timbers (faced with steel rails) were placed under the main booms, and iron rollers inserted between them and the lines of rails forming the ways; at the inner ends of the girders special trollies 25 feet long, resting on four solid cast-iron wheels 2 feet in diameter and four 3 feet in diameter, 8 inches broad, running on the rails of the ways. The intermediate supports were then removed, two single sheaves were attached to the rear end of the girder and two double sheaves to the abutments; two 1-inch chain tackles were rove through these, the falls being led to the rear of the girder and connected by rope tackles to capstans driven by two steam engines. There were also three 4-inch steel wire ropes rove through sheaves 28 inches diameter, which formed a hauling tackle between the outer end of the girder and the nearest point of the central cantilever; a series of rope tackles, led to three steam winches fixed at the last-mentioned point, completed the hauling over apparatus.

The first operation was to haul forward the girder 75 feet until its outer end projected 51 feet beyond the abutment. In this position it was possible to place, under the forward end of the girder, the pontoon by which it would be sustained in its progress across the river to the end of the cantilever, its final resting place.

These pontoons were (as before mentioned) used for the sinking of the river piers; they were of iron, each 225 feet long, 26 feet 6 inches wide, and 9 feet deep, stiffened by longitudinal and transverse bulkheads, and weighed 154 tons. After they had been brought together and secured at a distance of 27 feet, centre to centre, a massive staging of timber strengthened with double-headed iron rails was constructed upon them to support the girder at the proper height during transit, the pontoons themselves being adequately strengthened.

The height of this staging was fixed at about 50 feet above the expected low water level at the time arranged for the operation, any deficiency met with being made up by hardwood packing.

The draught of water of the pontoons with staging, etc., was $2\frac{1}{2}$ feet, and when supporting the girder, weighing 500 tons, 2 feet more.

A start was then made with the hauling operations, and the girder safely placed in position in about 5 hours in each case. During the transit the correct course was kept by warps attached to capstans on three barges moored both above and below the bridge.

Findhorn Bridge, Highland Railway, Scotland.

The viaduct carrying the Highland Railway across the valley of the River Findhorn is 1,336 feet long, and consists of a masonry abutment 88 feet long at each end, with two 25-foot arches and nine spans 125 feet clear, on piers varying in height from 66 to 130 feet. The railway is on a gradient of 1 in 60, and on a curve of half a mile radius.

The superstructure of each of the main spans consists of two independent open lattice girders 130 feet long and 16 feet deep, placed 16 feet apart, with cross girders and flooring resting on the upper booms.

After some consideration of the circumstances it was decided to make use of a form of travelling stages which (supported upon the piers) could be moved forward from pier to pier, and thus would provide in succession a platform for the erection of the steelwork of each span (*Figs.* 1 and 2, *Plate* VI.).

This travelling stage was formed of two main girders, 193 feet long and 18 feet deep, divided into 12 bays by verticals; the booms and diagonals which were subject to both tensile and compressive stresses were steel bars, flitched on each side with timber 12 inches by 12 inches and 10 inches by 10 inches; the verticals, acting only as struts, were timber 12 inches by 6 inches and 10 inches square, and were so fitted that by wedging up any deflection could be eliminated. The girders were framed, 9 feet apart centre to centre, by timber beams connecting the booms at each vertical, and the structure was braced and stiffened vertically and horizontally by steel rods with screw connections. At the rear end, and at a point corresponding to the distance between the centres of the piers, there were special cross beams and diagonal strutting by which the stage could be lifted by jacks as required.

When in position upon the piers it will be seen that this stage would permit the permanent girders to be constructed on each side and the cross girders upon them above it (*Fig.* 17, *Plate* III.).

To provide a support during the construction of the girders, steel joists 6″ × 3″, 10 feet long, were fixed at each vertical on the outside of the lower boom of each girder of the stage, projecting outwards at right angles to the latter; they were secured to these by steel straps and pins, and, at 6 feet from their inner ends, a 1¼-inch chain was connected with the top booms of the stage girders, and thus supported them horizontally. These joists were adjusted and kept in place laterally by iron rods between their centres, and were braced at each end to the bottom booms. Upon these joists was laid 4-inch planking, forming a platform.

This travelling stage was put together on the embankment at one end of the viaduct; and, when completed, two sets of rollers 4 inches in diameter, eight in a set, fixed in a steel frame, were placed at two points under each lower boom, affording at each point a bearing 9 feet long.

As the stage was 193 feet long and the clear span between the abutment and the first pier was 120 feet, the rear 73 feet was counterweighted by 40 tons of Kentledge.

The whole was then thrust forward by means of block tackle and winches, the total weight, including Kentledge, being 124 tons. As soon as the forward end of the stage reached the first pier it was blocked up, and the rear sets of rollers transferred there. The movement was then continued until the forward end overhung the first pier 63 feet.

The side platforms were now attached to the stage, and the work of erecting the permanent steel work proceeded with by the aid of a handcrane running on rails, laid on the top booms of the stage girders. Each permanent girder weighed 45 tons, and the deflection of stage did not exceed 2 inches.

On the completion of the steel work of the span, the rear end of the stage was specially strengthened, and a wheel on an axle fixed there on each side in such a manner as to run upon the inside edges of the lower flanges of the permanent girders; their maximum load was 30 tons, diminishing to 0 when the centre of gravity of the stage was over the rollers on the piers. On further movement the pressure would be reversed; and, to counteract this, a pair of guide wheels were mounted on the centre cross girder of the permanent structure, so that they engaged with the rails on the top booms of the stage girders on which the erecting crane had been run; thus, as the stage moved forward, the weight of the permanent steel work was utilized as a counterbalance. The motive power was provided by block tackle and hand winches, the tractive force required being about 13 tons.

When the forward end of the stage had reached the second pier it was blocked up and the rollers from the first pier inserted there; the movement was then continued until it was in position for the erection of the second span. The operations were repeated for each successive span until the whole of the superstructure was completed.

Where the superstructure of a large bridge has been put together at a convenient spot at the side of the river to be crossed, a method of placing it in position on the piers has sometimes been adopted similar to that used at the Tay Bridge, where the main spans were floated out and afterwards raised; in these cases the spans are put together on a staging of sufficient height, which, carrying the girders, has been floated to the piers on pontoons; the latter, being then partially sunk, permit the girders to take their bearing on the former.

Hawkesbury Bridge, Australia.

A good example of this procedure is afforded in the case of the Hawkesbury Bridge, which, 2,900 feet in length, completes an important link in the railway communication between some principal cities in Australia.

The superstructure, carrying a double line of railway, consists of seven independent spans of 416 feet, the girders of which are of the Whipple Truss pattern, 410 feet long and of 58 feet maximum depth (*Fig.* 3, *Plate* VI.).

One of the interesting features connected with this bridge is the unprecedented depths, 101 to 162 feet below high water, to which the caissons with which the piers are constructed were sunk. The site of the crossing of the Hawkesbury River (practically an arm of the sea) being very exposed, and the tidal current running strong, the method of construction and placing in position of the large spans was as follows:—

A pontoon, 335 feet long by 61 feet wide and 10 feet deep, provided with 44 water-tight compartments fitted with inlet valves, was constructed chiefly of Oregon pine; and upon it was erected a staging about 32 feet high, that, with the freeboard of the pontoon, being about the height of the underside of superstructure above high water (*Fig.* 4, *Plate* VI.). When the pontoon with its staging was completed it was towed over a gridiron of piles and sills specially constructed in shallow water, and sunk upon it by opening the inlet valves. Upon the staging were then erected (by the aid of travellers and hoisting engines) the girders of one span; when these were completed the valves were closed, and, as the tide rose, the pontoon floated, and (carrying its load) was hauled out to the position of the girders between the piers (*Fig.* 5, *Plate* VI.); when sufficiently secured the pontoon was lowered by the admission of water, and the girders left in their permanent seats. In order to permit of adjustment when approaching the piers the pontoon was made of a less length than the spans, the girders of which overhung at one end 63 feet, and had to be stiffened there by temporary iron ties and timber struts.

Ohio Connecting Railway Bridge.

The erection of the large span of the Ohio connecting railway bridge was accomplished in a somewhat similar manner, but there were some differences of detail in the work. The channel span consists of two main girders, 523 feet long, 65 feet maximum depth and 25 feet wide, weighing 915 tons; their undersides are 85 feet above the principal waterway, much used by unwieldy rafts and barges. A gridiron, 600 feet long by 100 feet wide, with the short side parallel to and distant 300 feet below the axis of the bridge, was formed in shallow water by driving piles in rows, each row being cut off at a level of 16 feet 6 inches above ordinary water level; upon these iron beams were laid, forming the foundation of the timber trestles of the erection staging; these trestles were 57 feet high, 80 feet wide at the bottom, and 32 feet wide at the top, and were securely braced with timber and special iron bars (*Fig.* 6, *Plate* VI.).

The members of the girders were hoisted up and put together upon this staging; when these operations were completed nine specially constructed barges, 130 feet long, 25 feet wide, and 8 feet deep, divided into longitudinal and transverse watertight compartments provided with valves, were placed in position between the rows of piling, so that special framework constructed upon the barges was exactly beneath the iron beams forming the foundation of the staging. In order to do this the barges had been partially sunk by admission of water. As soon as proper adjustments had been made the water was pumped out of the barges, which then rose and lifted the staging girders and all free of the piles. After securing the top heavy mass from overturning by wire rope guys to the head and stern of each barge, the whole mass was towed out and swung round into position between the piers. Water was then admitted into the barges, which then sank and left the girders resting on their permanent seats on the piers.

About two days were occupied in the operations of placing the barges in position, towing out and fixing the girders. The weight of staging and girders carried by the barges was about 1,800 tons.

VII.—Metal Bridges of Large Span Erected by Overhang without Support from Beneath.

Mississippi Bridge, St. Louis, U.S.A.

Probably the earliest if not the boldest example of this method of erection is the St. Louis Bridge over the Mississippi River. This fine bridge is double-decked, carrying two lines of railway below and a roadway on top; it consists of three steel arches, of which the centre has a span of 520 feet, that of the others being 502 feet. The cost of the steel in the superstructure was £360,000 and that of its erection £35,500. Each arch consists of four trusses firmly braced together, resting on two lines of steel tubes 12 feet apart vertically; the tubes are 18 inches in diameter, in lengths of about 12 feet, joined by screw couplings; flat steel bars between the couplings brace the two lines together.

The first portions of the arch tubes were placed in position on each side of the masonry piers on staging, and, when securely fixed to the skewbacks, furnished support for the succeeding portions, which were raised from barges in the river by the aid of derricks fixed on that completed. At the end of the third lengths, or 36 feet on each side of the pier, it became necessary to introduce support, which was given by connecting them by steel wire cables passing over the piers. Similar cables were added at the ends of the sixth and ninth lengths (*Fig.* 1, *Plate* VII.).

As the building-out continued, further supporting cables were introduced, which, to render more effective support, were passed over temporary timber towers erected on the piers (*Fig.* 2, *Plate* VII.).

The last support was given by a secondary system of cables resting on a tower built up from the coupling joint on the upper tubes, at a point about 150 feet from the pier. *Fig.* 18, *Plate* III., shows generally the arrangement of these temporary supports.

Blaauw Krantz Bridge, Cape Colony.

The construction of a railway across the Blaauw Krantz gorge in Cape Colony, which is about 600 feet wide and over 200 feet deep, with precipitous rocky sides, was an interesting problem both as regards design and erection.

This was solved in a very satisfactory manner by the building of a viaduct, the iron superstructure of which, 480 feet long, consists of a double cantilever 144 feet in length on each side of a central framed structure of arched form, having a span of 220 feet and a rise of 90 feet.

The piers supporting in the centre the double cantilevers were first built up; then the cantilever arms were extended in both directions (*Fig.* 3, *Plate* VII.). On reaching the abutments their inner ends were there secured; cranes were then put up at their outer ends, by which the legs or haunches of the arch were erected in a vertical position; when these were sufficiently advanced they were inclined towards each other, and then kept in position by temporary ties (*Fig.* 4, *Plate* VII.). The members of the central portion joining them up were put in place by overhang, no supporting scaffolding being made use of (*Fig.* 5, *Plate* VII.). Wire ropeways, stretched across the gorge, were employed to bring the material to the cranes.

Lansdowne Bridge, N.W. State Railway, India.

The Lansdowne Bridge carries a single line of the North Western State Railway of India by one span of 820 feet across the River Indus, which here has a depth of 70 feet at low water, and a current at times of nine miles per hour. These latter conditions, together with the contingency of floating débris of large dimensions, precluded the use of staging in the river, to give the necessary support during the erection of the steel superstructure of the bridge, which consists of a single cantilever of 310 feet projection on each side, with an independent girder 300 feet long between them.

During the erection three methods were adopted, timber staging for a portion of the cantilevers, building out for the remainder, and temporary platforms, slung between points on the cantilevers and between the cantilevers themselves, for the horizontal ties and the independent girder respectively.

The staging (*Fig.* 6, *Plate* VII.) served to assist in the erection of, and to support, the principal columns or backbone, 170 feet long, the back ties, 290 feet long, and the first struts, 230 feet long, of the cantilevers. It was of timber and was carried up sufficiently high to enable the derricks used to put the steelwork in place. The inclined portion of the lower member was erected by the aid of a temporary girder attached to the outer support of the timber staging.

Temporary platforms (*Fig.* 7, *Plate* VII.) were slung on wire ropes between the tops of main vertical columns and of the first struts. These wire ropes were kept rigid by being formed into trusses with timber compression members and adjustable wire rope ties. These platforms served to carry a travelling crane, by which the horizontal ties, each 123 feet long and weighing 80 tons, were erected, as well as to support those members during the process.

The remaining portions of the cantilevers were erected by overhang, being kept in position by temporary ties, the different parts being brought into place by the aid of wire ropeways stretched across the river, and by derricks on staging carried by large barges moored in the stream.

For the support during erection of the centre girder a platform was provided by the construction of a temporary bridge between the noses of the cantilevers (*Fig.* 8, *Plate* VII.); it was of the inverted bow-string type, 197 feet long, weighing 56 tons, and consisted of flat bar bottom members, channel bar top members and struts, with round bar bracing. The parts of the centre girder were placed in position by the wire ropeways and the derricks on the barges. At all times during the process of erection the unfinished portions of the structure were adequately secured, in most instances by wire rope ties. The steelwork cost 1,701,000 rupees; and in addition the cost of erection, including special plant, was 570,000 rupees, of which about 15 per cent. was for timber.

Forth Bridge, Scotland.

The Forth Bridge, unique in design and unprecedented in dimensions, naturally presents many interesting features as regards the methods adopted for its erection. The main structure, 5,322 feet in length (out of a total length of 8,296 feet), consists of two spans of 1,710 feet and two of 680 feet; the superstructure of steel consists of one double cantilever, 1,628 feet long, two of 1,514, and two independent girders, 347 feet long. The highest portion of the structure is 361 feet above high water; the maximum headway for navigation is 151 feet; and the rails are laid at 157 feet above that level.

The total weight of riveted steelwork in this portion is 50,692 tons.

The methods of erection made use of may conveniently be grouped as follows:—

Group A.—Erection on timber staging, giving support from the ground by the use of ordinary derrick cranes.

Group B.—Erection by special appliances placed on extensive platforms, which varied in position according to the progress of the work.

Group C.—Erection by means of special cranes, which, resting on the members, enabled the latter to be extended, and in turn became the support of the former.

Group A (*Plate* X.).—The portions dealt with in this group were the upper and lower bedplates of the cantilever, the junction pieces or skewbacks resting on the latter, with the tubular lower members and bracing connecting them; these were put together on timber staging, the principal members pointing upwards and outwards to the extent of about 40 feet. The component parts of all these plates and bars were put in place by the aid of ordinary derrick cranes placed near ground level, and riveted up *in situ.* The amount of timber used temporarily in this group was 40,000 cubic feet. The steelwork weighed 7,300 tons.

Group B (*Figs.* 1 and 2, *Plate* VIII.).—In this were included those portions of the structure forming the central part or backbone of the cantilevers over the pins and the lower half of the first bay of their projecting arms, and comprised principally of vertical columns 320 feet in length, the main horizontal ties between them 155 and 270 feet long, diagonal struts 315 to 375 feet long, with the various bracing connecting them together; a total weight of 15,000 tons.

The principal features of the method adopted were large platforms or staging amply securing the safety of the workmen, and special appliances for placing the parts in position with as little as possible interruption from the weather. At each cantilever two platforms were provided, one on each side of the axis of the bridge. They were 20 feet wide and 350 feet long at the centre cantilever, and 200 feet long at the others; and were composed of timber planking and joists, which rested on two longitudinal girders, one on each side of the vertical column; these in turn were carried by cross girders passed through the northern and southern piers of the vertical columns. A double set of upper and lower box girders within each vertical column were supported by pins passed through their ends and the webs of the **I** beams forming part of the vertical columns. Hydraulic rams, $13\frac{1}{2}$ inches in diameter, capable of lifting 240 tons at a pressure of 30 cwts., were inserted between the box girders, the upper of which supported the cross girders carrying the platform girders. On admitting the water to the jacks, the pins in the upper box girder having been first removed, the girders and platforms were raised the stroke of the jacks, the pins were then inserted in the upper box girder, and those from the lower removed. The action of the jacks being reversed, the latter were drawn up; and, when the pins were inserted in it, the operation of lifting was resumed until the platforms were raised by successive steps sufficiently (generally 16 feet) for the resumption of building the members, the plates and beams of which were raised to the level of the platforms by ordinary hoists, and then placed in position by Goliaths worked by hydraulic power (*Fig.* 2, *Plate* VIII., and *Plate* X.).

In this way the centre portion of the cantilever was built for a height of 281 feet in about 6 months (*Plate* XI.); at this level the platforms were strengthened, and upon them were put together the massive horizontal ties, each weighing about $1\frac{1}{2}$ tons per foot run (*Fig.* 1, *Plate* IX., and *Plate* XII.).

A movable framework built in sections 48 feet long and 20 feet square, carrying a hydraulic crane on the top, was used for building 160 feet of the lower member, which was a tube 12 feet diameter, weighing 2 tons per foot. The crane put in place the parts of the tube; and then, resting on it, moved the back sections for the framework to the front, and so crept out (*Plate* XIII.).

For the erection of the lower portion of the first strut, and the first vertical tie and support to the internal viaduct, platforms similar to, but smaller than, those first described were used (*Fig.* 1, *Plate* IX., and *Plate* XII.).

Group C.—The experience gained during the erection of the portions of the cantilevers included in Group B showed that great modifications could be made in the appliances there made use of. The ability of the men to work safely under ordinary conditions of weather, as well as the ease with which large and heavy material could be raised great heights, permitted the use of other apparatus, which enabled the large and heavy platforms especially to be dispensed with, thus reducing both the time taken and the cost of the operations.

With the exception of the first bay of the lower members, the first 120 feet of the internal viaduct, and the lower portion of the first struts, the whole of the principal members of the arms of the cantilevers and the independent girders were erected by the special apparatus now to be described (*Fig* 2, *Plate* IX.). One special crane was employed to build the top members and the upper halves of the struts and ties and the central girders. The other traversed along the internal viaduct and dealt with the remainder of the work.

The top member crane was provided with a horizontal jib 35 feet in length, which could be slewed through an arc of 230 degrees, and along which suspending pulleys ran. The lifting of the material was effected by a steam winch, the drum of which accommodated 400 feet of $1\frac{3}{4}$ wire rope.

This crane was supported on a carriage formed of two steel cross girders strongly braced, which rested on the upper surfaces of the angle bars connecting the vertical webs to the flanges of the booms of the top members, and along which it could be traversed by powerful screws. Beneath the top member, and strongly attached to the carriage, was suspended on four longitudinal girders a roomy platform of timber, 76 feet long and 45 feet wide (*Plate* XIV.).

The crane raised into position, plate by plate and bar by bar, the parts of the member to be built, and the men standing on the platform bolted them together; when all within its reach had been dealt with, the carriage was slid down the top member, and operations resumed until the cranes met at the centre of the central girders.

The internal viaduct crane (*Fig.* 2, *Plate* IX. and *Plate* XV.) consisted of two masts and jibs of the derrick type, the former in line transversely to the axis of the bridge and 16 feet apart, braced strongly together and secured to a movable timber frame traversed along the outer rail trough of the internal viaduct. To lessen the weight at the point of operation the lifting rope was led some distance back to a steam winch on the finished structure.

To provide the necessary standing room for the men at work on the lower members, and at other places where necessary, light timber stages only were required, which were easily shifted by the viaduct cranes.

Wire ropes, timber struts, and light temporary girders were made use of to secure the parts of the unfinished structure against damage from their own weight or the effects of wind, which often reached as great a pressure as 28 lbs. per foot.

Proposed English Channel Bridge.

Among the many engineering schemes of modern times no doubt the boldest is the proposal to connect England with the Continent by means of a bridge across the Channel, between a point near Dover and Grisnez, on the French coast.

This project has for many years been the study of eminent engineers in France, and every detail of its design and construction has been worked out with the greatest minuteness.

The bridge was to be about 21 miles in length, with 72 piers, carrying 72 double cantilevers, 1,272 feet long, and 37 intermediate girders, 410 feet long, the spans being 1,640 and 1,312 feet alternately.

The piers, of masonry, up to 69 feet above low water with steel columns above, were to be built by means of caissons, 170 feet long and 100 wide, placed in position with the aid of temporary structures similar to those used at the Tay, called movable platforms, which, rectangular in form, with a central space, were to be floated into position, and retained there by lowering large tubular legs to the bottom of the channel, which, when suitably secured to the platform, provided the required stability.

The height of the piers above low water was to be 205 feet, the maximum depth below that level being 170 feet.

Upon the completion of a pier the movable platform was to be taken to the site of another, and other movable stages similar to those used for the pier were to be floated and secured in such positions along the axis of the bridge that four covered the length of a cantilever and half an independent girder, about 1,500 feet (*Fig.* 19, *Plate* III.).

These stages were to be extended upwards to near the level of the underside of the bridge, 205 feet above low water; girders were then to be placed between them, which were to support the superstructure during erection, as well as provide a continuous path for a large traveller to put together its component parts.

This is a magnificent example of the method of erection so much favoured by French engineers for their large bridges. It no doubt affords facility and security, and, to some extent, economy of time; but possibly in this instance would not have been found economical as regards cost.

The estimated cost of the 905,000 tons of steel was £11,000,000; that of the erection was about £6,000,000 in addition.

With others I was consulted by the Channel Bridge Railway Company, and I suggested a modification of this method of erection, which the experience gained at the Forth Bridge appeared to justify; this was as follows:—

One of the movable platforms should be placed on the 1,640 feet span side of each pier, leaving a space between the two platforms of 900 feet. A portion of the structure temporarily supported should be built both on the pier and on the platform, and, when sufficiently advanced, these should be joined up. The structure now would have a good base, and could be easily and by simple appliances extended upwards and outwards ; when and where necessary, strong temporary ties and struts would be introduced, chief among which would be a back tie between the permanent work and the platform.

The cantilevers over the 1,312-foot span would be joined up, and those on the 1,640-foot span completed ; and when that stage was reached the independent girders could be built out as prolongations of their arms.

Fig. 20, *Plate* III., shows the proposed progress of the operations ; the different broken lines their successive stages, the temporary ties being indicated by heavier broken lines.

LIST OF FIGURES AND PLATES.

PAPER V.

DEMOLITIONS IN SAVAGE WARFARE IN INDIA.

BY CAPT. S. H. SHEPPARD, D.S.O., R.E.

PREFACE.

IN all active service on the Indian Frontier, the Royal Engineer officer is continually called upon to demolish village defences, towers, and walls. Such operations, though exceedingly simple and easy to carry out for anyone who has had experience in the subject, may not infrequently be troublesome and dangerous to a beginner, owing to the fact that nothing has ever, I believe, been printed on the subject from which data may be obtained. The object of the following notes is to supply these data. I do not write as an authority on explosives; these notes are merely the outcome of a certain amount of personal experience in demolition work, and are intended to assist a man who has never blown up a tower to do so quickly and safely.

I have included a few remarks on *gunpowder*, though this will seldom be used in future; the agent will generally be *guncotton*.

Making up a Gunpowder Charge.

Here there are only three things to be considered—fuzee, fuze and charge.

(*a*). In case you have no fuzee or port fire, do not attempt to light your fuze with the ordinary match. I once saw a brigade halt for 20 minutes, waiting for a tower to be blown up, while an officer was trying to light his fuze in a high wind with safety matches. By lighting a very small fire, and using the red-hot end of a stick, you can get a perfect fuzee in a couple of minutes.

(*b*). The fuze may be black, grey, pepper and salt, or red; the last is the best, and in most general use. But whatever the colour, make an absolute rule of testing a small piece out of each box or length and never, if you can possibly avoid it, use a doubtful piece; missfires caused by defective fuzes are the most dangerous of all. Most fuzes burn a little slower than the yard per minute laid down; this does not matter so long as they burn perfectly steady, not by fits and starts, and end with a sharp hiss.

(*c*). The charge is generally put into a sandbag; except for walls and rocks, where what is required can be poured in.

Remember to tie a couple of loose knots in the end of the fuze that is put into the charge before you tie up the mouth of the sand-bag; this will prevent the fuze being pulled out of the bag during tamping operations.

It is hardly necessary to say that a gunpowder charge should be well tamped, especially in a tower.

Making up a Guncotton Charge.

Here there are five parts—fuzee, fuze, detonator, primer, and charge; an extra minute or two spent in attention to minute details will well repay you, and save many a missfire.

(*a*) and (*b*). Have been already dealt with.

(*c*). The No. 8 detonator is kept in tin boxes of 25; always, if possible, test one out of every box.

One sometimes finds, when affixing the fuze in the detonator, that it sticks half-way down, but you can generally "screw" it in without using much force; it is important to get the fuze well home. Then bend or nick the top of the hollow part of the detonator, to keep the fuze in.

(*d*). The primer should always be of the varnished pattern, in water-tight tins. One sometimes has to use loose, unvarnished primers, but they are troublesome, as they suck up any moisture they can and are seldom to be depended upon. The best way to dry them, if they get wet, is in the sun, or by putting them in some dry lime; the latter dries them quickly and thoroughly.

The hole in the primer very seldom fits the detonator; this should be carefully "rectified" until you can easily push (*not* screw) the detonator in; the shoulder of the latter should be about $\frac{1}{4}$ inch above the top of the primer when fixed.

When fixing the primer in the slab, take care it fits tightly; put in little wooden wedges, if necessary, to ensure this.

(*e*). The guncotton slabs are generally placed on top of each other, and tied together. Take care that the top two slabs have their holes together, as the end of the detonator projects through the primer into the hole of the slab below.

The slabs should not be so dry as to be crumbly, nor so wet as to exude drops of water when pinched.

I personally invariably use two primers, detonators, and fuzes in a tower, or in any considerable charge. I have often heard one detonator pop and fail, and the other explode the charge.

A charge should be made up in this way:—First "rectify" primers and place in slabs, tie slabs into charge, and place in position and tamp on all sides except where primers are; then fix fuze in detonator, and last of all detonator in primer.

Remember that guncotton very readily catches fire; the charge, when tamped and ready, should be carefully covered with earth to prevent this.

It is not really necessary to tamp guncotton on all sides; *e.g.*, in a hole in a tower, tamp all round and above, but do not fill up the hole A towards the mouth; just cover the front of the charge with earth (*Fig.* 1).

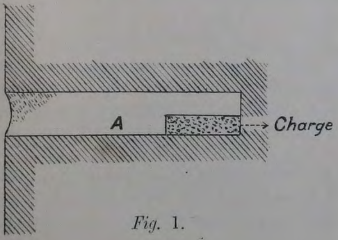


Fig. 1.

Demolishing Walls.

If the wall be fairly thin, make two holes half-way up, put a beam across, pass a rope through each hole round the beam, and pull.

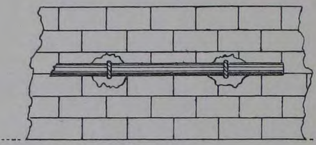


Fig. 2.

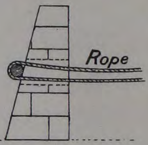


Fig. 3.

But if ropes and men are not available, or if the wall is thick, say 4 feet at base, it will have to be blown down.

Dig holes as near base as possible, sloping down at an angle of 45° or so, and about 6 feet apart if the wall is 4 feet thick; and put 5 or 6 lbs. of guncotton in each hole.

The best tamping material is wet clay. Cut your fuzes so that each explosion shall be distinct from the other and you can count then easily; if a lot go off together one is never sure whether all have gone off, or whether there has been a missfire.

Should a wall which is held by the enemy have to be breached, the charge must be hastily laid at the foot of the wall and just covered over with sandbags to prevent it catching fire; 20 lbs. of guncotton, when laid in this manner, blows down a 10-foot breach in a wall 3 feet thick and 10 feet high.

Demolishing Towers.

This is a big subject, and a most important one. We will first speak of deliberate demolitions, where one has plenty of time and wishes to absolutely *level* the tower, and secondly of the far more usual case of rapid destruction, where your quickness may make a great difference to the officer commanding your column or brigade.

(*a*). *Deliberate Demolition.*—Here towers need be divided into two classes only, hollow and solid based, the latter being the more common.

To blow up a hollow tower is a simple matter. Go inside, dig a hole 2 feet or 3 feet deep in the centre of the floor and put in your charge, tamping it very firmly all round and covering it with earth

(*Fig.* 4). The whole thing should not take more than 15 minutes at the outside.

Hollow towers may be square or round; a great many were met with in the Khyber in 1897–1898; the treatment is identical.

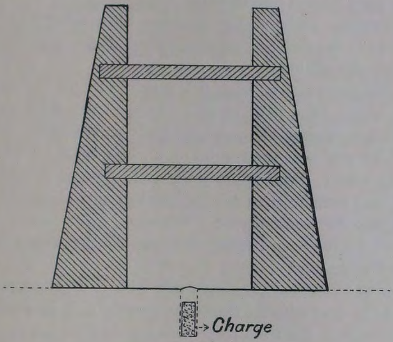


Fig. 4.

Solid-based towers must be dealt with differently. Here the base must be pierced from outside; this is a much longer business, and I have known an hour or more spent over one such operation; besides which the inside of the base is often composed of rather loose stones, which keep on coming down and filling up the hole. However, when properly carried out, very thorough demolition is the result.

Bore the hole from the centre of one face, straight in for at least 5 feet (*Fig.* 5).

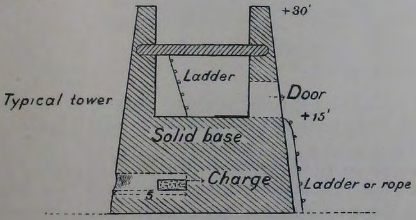


Fig. 5.

(*b*). *Rapid Demolition.*—The secret of success in this is *to treat every tower as a hollow tower*, and blow it up from *inside*.

The only exceptions are :—

(i.). In the case of towers solid for nearly the whole of their height, which are very rare except in fields.

(ii.). When the ladder to the door has been taken away, and you cannot find any way of scaling the wall. These must be treated as in deliberate demolition.

But in the generality of cases it is possible to get inside. In such cases simply dig your hole in the centre of the floor as in hollow towers ; this is very quick, and practically as effective.

I found latterly that the results of blowing up a "typical tower" in this way were :—Four upper walls and 5 feet of base completely blown off, and remainder of base so cracked and shattered as to be useless as base for a new tower.

The *charges* have to be slightly heavier, but the saving in time and trouble is tremendous.

One kind of tower was frequently met with in Waziristan which was rather hard to deal with in this way at first ; it is similar to the typical tower, but has a staircase running up through the solid base (*Fig.* 6).

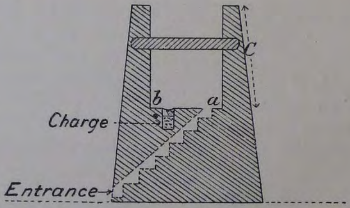


Fig. 6.

Here the hole for the charge cannot be dug in the centre of the floor, as it might break into the staircase, so place it half-way between opening *a* and wall *b*. Unless a fairly heavy charge is used the wall *C* will sometimes be left standing ; but it will be cracked and shaky, and the whole base down to the entrance will be ruined, so that, although the work may not *look* neat, all practical results will be achieved.

During the late "raids" in Waziristan, I personally blew up 25 towers, which were either of "typical tower" type or of the type with staircase just described. All, without exception, were operated on from inside; all* were completely shattered; and the average time occupied was certainly not more than 15 minutes from first entry into tower to completion of preparations, including digging hole, making up, fixing, and tamping charge.

Another advantage of this method is that trained labour is not necessary; any man can dig a 3-foot hole in a floor, but it takes men accustomed to the use of crows and jumpers to bore out a 5-foot horizontal hole in a tough stone base in reasonable time.

Mills.

One is often ordered to blow up small native mills. These generally consist of a couple of heavy millstones in a hut about 8 feet square. Seven to 10 lbs. of guncotton, placed on top of the millstone and tamped as far as possible, will bring down the whole concern and break the stones.

Charges (Guncotton) for Towers.

I do not pretend that the data given below are infallible; but they are the outcome of personal experiment, successful and unsuccessful; and if they err it is certainly on the side of liberality.

It must be borne in mind that one cannot afford to *fail* on active service when carrying out demolitions. When in doubt it is always better to add a pound or two of guncotton and be on the safe side; it is only the man who, by careless loading, has a large percentage of missfires that really *wastes* his stores.

The largest and strongest towers that have been met with in late years were those below Landi Kotal in the Khyber, in 1897–98. These were circular and hollow, and ran to 45 feet in height and 24 feet outside diameter at base, the walls being over 4 feet thick at base.

They were destroyed by the "hollow tower" system; a 30-lb. charge brought down every particle of the tower; but a 20-lb. charge only blew out a portion of one side and cracked all the rest (which, however, fell in a few days in heavy rain); 25 lbs. would

* Except two, when guncotton was running short and 15-lb. charges were used, and one wall was left standing in each case.

have been just about right, and I have personally never put more than this in any tower.

For deliberate demolition of a "typical tower," measure diameter or one side of solid base roughly in feet; add 4 feet; the total will give the number of pounds required for the charge. Thus a 15-foot square tower would take 19 lbs.

For rapid demolition by the "hollow tower" system, add another pound or two. Twenty-five towers blown up in Waziristan by this system averaged exactly 20 lbs. apiece; they were all of "typical tower" type or with interior staircase, and were all between 14 feet and 18 feet wide at base.

Common Causes of Missfire.

(*a*). Neglect of testing fuze in each box, and a detonator from each tin.

(*b*). Damp primers.

(*c*). Too wet guncotton. A 2-inch primer will explode anything, but I have known a 1-inch primer fail when the guncotton was very wet (it was *old*, too, in this case). But the charge may be absolutely dripping, so long as you have one dry slab on top with primers in it.

(*d*). Charge catching fire.

(*e*). Primer not being well fixed in slab; always ensure tight contact.

(*f*). Detonator not being pressed in primer; if only the *tip* is in, the primer won't explode.

(*g*). Fuze not being well home in detonator.

(*h*). Fuze being cut by a sharp stone during careless tamping.

(*i*). Detonator being pulled out of primer during tamping.

NOTE.—*This paper was originally published at Roorkhee as an "Instructional Circular" of the Bengal Sappers and Miners.*—[ED.].

PAPER VI.

NOTES ON PLATELAYING.

By Captain P. G. Twining, R.E., Captain P. Maud, R.E., and Captain W. H. Beach, R.E.

PREFACE.

The following notes on Platelaying are principally compiled from reports of Capt. Maud and Capt. Beach, R.E. on the work of the 2nd and 6th Companies, Bengal Sappers and Miners, on the Ludhiana-Dhuri-Jakhal and the Kohat-Kushalgarh-Thal Railways, supplemented by a few additions from my personal experience. The first part contains Capt. Maud's report in its entirety.

It is hoped that this pamphlet may prove useful to any officers of the Corps who read it. For those who wish for further information on the subject of points and crossings, I would recommend *Notes on Permanent Way Material, Platelaying, and Points and Crossings*, by W. H. Cole, published by E. & F. N. Spon, London.

P. G. Twining, *Capt., R.E.,*
Superintendent of Instruction, B.S. & M.

CONTENTS.

PART I.

(By Capt. P. Maud, R.E.).

Work of the 2nd Company, Bengal Sappers and Miners on the Ludhiana-Dhuri-Jakhal Railway, December, 1900, January, February, and March, 1901.

LUDHIANA-DHURI-JAKHAL RAILWAY.

Orders were received in November, 1900, that the company was to be employed on platelaying on the Ludhiana-Dhuri-Jakhal Railway, and I was put in communication with the Engineer-in-Chief.

This railway is an 80 miles chord, joining Ludhiana on the N.W. Railway with Jakhal on the Delhi-Batinda Railway (S. Punjab), and crossing, at Dhuri in the middle of its length, the Rajpura-Batinda Railway. The railway is what is called by rail engineers a cheap line. It has no big bridges, the country is very flat; and materials and stores can be got by rail to the two ends and the middle of the line.

In its length of about 80 miles this chord line, starting from Ludhiana, passes through the following territories in the order named:—Maler Kotla State, Patiala State, Naba State, and Jind State. It was constructed at the request of the Durbars of Maler Kotla and Jind, who are paying for it; when completed it will be worked by the N.W. Railway.

Preliminary Instruction.

Owing to delay in the arrival of rails from home, the 2nd Company did not start for Dhuri until December 10th. In the meantime I ascertained from the Engineer-in-Chief that the permanent way consisted of 75 lbs. F.F. rails, 30 feet, spiked to deodar sleepers, bearing plates on joint sleepers only; gauge, 5′—6″. The time till the rails arrived was utilized in instructing the company in platelaying with F.F. rails spiked to wooden sleepers. The company had practically no previous experience of platelaying, except what each man had learnt as a recruit on his field work course and from occasionally laying a temporary line for Pur Artillery practice camp; and so, although the material available was insufficient to practice a drill by which platelaying could be systematically carried out, the men were instructed, whilst waiting for the arrival of the rails, in a few of the essentials of good platelaying, such as straight spiking in pairs, placing sleepers at right angles to the rails, keeping augers vertical when boring sleepers, and accurate gauging.

We left Roorkee on December 10th, and arrived at Dhuri on the 11th. After some persuasion the station master at Dhuri allowed the eight vehicles, which the company occupied, to be run on the construction line, and we went straight on to the Maler Kotla side rail head, which had then reached Maler Kotla. The base was at Dhuri, from which rail heads were being run outwards. Platelaying, by trolley only, was also in progress from Ludhiana and from Jakhal towards Dhuri. The Maler Kotla rail head was being run by a permanent way sub-inspector with about 350 coolies. The sappers joined this party and were mainly employed on fishing, boring, spiking, and lifting and packing the line enough to allow an engine to pass over it; and all had a turn at rail carrying, unloading trains, and loading materials on trolleys. All the naiks worked with the sappers, native officers and havildars superintending.

Sappers Working by Contract.

The coolies remained under the permanent way sub-inspector, and were almost entirely employed on loading and unloading and trolleying. This arrangement soon proved unsatisfactory, as the supply of materials was not systematically carried out and checks occurred; so I suggested to the Engineer-in-Chief that I should take charge of the whole rail head and work on contract, engaging enough coolies to lay what he wanted (*i.e.*, 1 mile a day). The advantage in this was that the rail head would be under one control; and the sappers and naiks, who had hitherto been working with their hands, would be given separate charges, as inevitably would be the case on service.

The Engineer-in-Chief agreed to this. If I had been fortunate enough to have had another officer with me I should certainly have proposed undertaking the loading of trains at the base—Dhuri—, as I had already found out that this part of the work ought also to be under the control of the officer running the rail head if the work was to be run smoothly and without checks.

I should add here that, on arrival on the line, I set all the sapper-artificers to work at their trades in the base workshops. There the smiths and carpenters, the former specially, were given plenty of instructive work of a nature which they would not usually come across.

The masons were sent to Sanam, where a bridge with eight or nine masonry piers was being built. As the work was being done by contract they were employed as supervisors to keep the contractor's work up to the mark, and they worked well in the interest of the railway.

Coolie Labour.

To return to the rail head. When I took over charge nearly all the regular platelaying coolies deserted, having been invited to do this by some supervisors whose services I did not require. A few remained and were formed into gangs. I made up the number to 240 with coolies from the surrounding villages. The coolies had not handled a rail before and were inexpressibly stupid, and several of them got injured. They would not work at a greater distance than about 5 miles from their village, and consequently I had to be continually forming new gangs. Later on many of the old railway coolies returned for work.

The 240 coolies were formed into gangs of 20 under their own mates, with a N.C.O. in charge of two or three gangs. I soon saw enough of platelaying to be able to make out a sort of drill for the sappers (who were now exclusively employed on platelaying proper) and to give each coolie gang definite work to do, the mate being responsible for its being carried out to time.

As my experience improved I slightly altered this drill as it is laid down here, until it worked really well.

Rapid Platelaying.

To effect rapid platelaying the following points are essential :—

1. No man should be armed with more that one tool ; each must know exactly what his work is and must do that only, as in pontoon drill.

2. The parties of rail carriers, fishers, borers and spikers, etc., must be so balanced that the work proceeds evenly ; and the whole of the platelaying should occupy as little length of line as is consistent with having plenty of elbow room for work.

3. "Leads" of all sorts should be reduced as much as possible, especially that of the rail carriers. The shorter their journey the quicker will the rails arrive at rail head. If the lead becomes long,

owing to the parties straggling out and the trolleys not being able to keep near rail head, the fault cannot be satisfactorily corrected by increasing the rail-carrying parties, as that would mean great interruption of spiking.

There is only just room between the outside of the sleepers and the edge of the bank for the rail-carrying party to move, on which account the spiker's work is being perpetually stopped. A pair of spikers have just got a sleeper in position at right angles to the rail and held up to it by their lever man, whose bar sticks out at right angles, when along comes a party of rail carriers, the leading man yelling the native equivalent for "By your leave." They have right of way, and so the lever man has to slip out of the way with his lever and chock, as no tools may be left on the rail carriers' path; the sleeper falls and, after the passing of the rail carriers, perhaps 20 seconds to half a minute is again spent in placing it in position for spiking. From this it will be seen how important it is to keep as much of the spiking work behind the material trolleys as possible.

For some time I followed the practice of the platelayers I had seen on the line and fully spiked the line before running the material trolleys over it. This meant a terrible long lead for the rail carriers and small material distributors, so I gradually reduced the number of spikes in the rails over which the material trolleys were allowed to be run for a short time. I even ran them over the rails simply laid to gauge on the sleepers and fished but not spiked. This, however, did not pay as, owing to the unevenness of the road and the varying gauges of the trolleys, some were always coming off the line, causing great delay. Finally, the least number of spiked sleepers which I found necessary for safety was three to each rail, the second from each end and the middle sleeper.

The sleepers as brought from the base were adzed, to give the rail the necessary tilt, but were only bored one side. The Executive Engineer of the line said that it was difficult to maintain true gauging if the sleepers were bored both sides previously before being laid, so for some time I followed his advice and gave much valuable space to the augermen.

However, after some time I tried the experiment of boring the sleepers in advance of the rail head, giving the augermen a "firman," consisting of a board with a peg in it to fit into one of the holes already bored and two holes in the other end, through which punch holes were made in the sleepers, into which the augerman placed his auger to bore. This I found answered admirably. The spikers who had to gauge their rail by the one already spiked worked much quicker; the gauge was kept, I think, more accurately than before; and all the augermen were out of the way 30 to 50 yards ahead of the front rail. This gave everyone elbow room and shortened the lead.

The sleepers themselves were carted by a contractor from the tip to rail head, and were roughly spaced on the road ahead of the plate-laying.

A N.C.O. ahead of rail head used to make rough marks on the road every 10 yards, where rail joints would come; and he saw that the contractor's coolies threw the required seven adzed sleepers and two unadzed joint sleepers in every 10 yards space.

The ordinary sleepers were adzed to give the rail the required cant inwards and were bored on one side only.

The joint sleepers (*i.e.*, those placed on either side of the rail joints) were not adzed, as the required cant was given in the bearing plates, which were used on joint sleepers only; nor were they bored as, owing to slight inequalities in the spike holes in the bearing plate, it would be difficult to fit the four holes of the bearing plate over four holes bored in the sleeper.

The adzing of the ordinary sleeper is shown in *Fig.* 1.

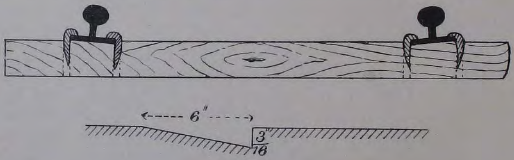


Fig. 1.

The spike holes are bored in the sleeper at the bottom of the adzed slope; the slope of adzed portion was as shown in section; this gives the rail an inward cant of 1 in 32. (Cole says this cant should be 1 in 20).*

* Note by Superintendent of Instruction.—It is a question whether, in adzing sleepers, the inside edge of the adze marks should correspond with the inside edge of the foot of the rail.

In many cases the rail does not quite coincide with the adzing and does not sit properly until after a train has run over it. This means that the inside spikes will not be properly driven home.

The following table gives the sub-division of a platelaying party that I found most convenient for work :—

No. of Party.	Place.	N.C.O.'s.	Sappers.	Coolies.	Mates.
	1 N.C.O. and 1 sapper, placing left rail alignment staffs in front of rail head and measuring to see if short rails are necessary to avoid joints on level crossings and on bridge sleepers ...	1	1	—	—
1st Party.	In charge 1 N.C.O.	1	—	—	—
	Sapper marking rails	—	1	—	—
	6 sappers placing rails in position and expansion pieces, with 4 hammers and 2 levers for spiking when check occurs on supply of rails	—	6	—	—
	4 sappers fishing right rail ; 1 coolie leverman ...	—	4	1	—
	4 sappers fishing left rail ; 1 coolie leverman ...	—	4	1	—
	8 sappers spiking 2nd, 5th and 8th sleeper, right rail ; 4 levermen	—	8	4	—
	8 sappers spiking 2nd, 5th and 8th sleeper, left rail ; 4 levermen	—	8	4	—
	5 sappers, augermen, boring sleepers 2nd, 5th, 8th right rail	—	5	—	—
2nd.	In charge 1 N.C.O.	1	—	—	—
	2 sappers placing bearing plates and 2 levermen	—	2	2	—
	8 sappers, augermen, 8 holes per rail joint sleepers, left rail	—	8	—	—
	16 sappers, augermen, 16 holes per joint sleepers, right rail	—	16	—	—
	20 sappers, spikers, 16 spikes per rail, left rail ; 10 levermen	—	20	10	—
	22 sappers, spikers, 16 spikes per rail, right rail ; 11 levermen	—	22	11	—
	2 sappers, wrenchmen, finishing fishing, left rail	—	2	—	—
	2 ,, ,, ,, ,, right rail	—	2	—	—
3rd.	Straightening party, in charge 1 N.C.O.	1	—	—	—
	10 coolies, levermen (or 6 sappers if available) ...	—	—	10	—
4th.	Lifting and packing party, in charge 1 N.C.O. ...	1	—	—	—
	40 coolies (occasionally some sappers)	—	—	40	—
	2 sappers, carpenters, repairing hammer handles	—	2	—	—
	2 ,, throwing rails from trolleys	—	2	—	—
	1 sapper oilman for trolleys	—	1	—	—
	15 small boys distributing small material (bolts, spikes, fish plates, and bearing plates). 1 boy sitting among the bolts on the first trolley, oiling bolts and nuts.	—	—	16	—
	1 sapper in charge of above	—	1	—	—
	1 N.C.O. in charge of all tools	1	—	—	—
	1 ,, ,, unloading trolleys at rail head and despatching empty trolleys...	1	—	—	—
	1 N.C.O. in charge loading trolleys at tip ...	1	—	—	—
	1 N.C.O. and 4 men follow behind platelaying, and correct all mistakes such as sleepers not square, spikes driven in crooked, etc.	1	4	—	—

TABLE—*Cont.*

Place.	N.C.O.'s.	Sappers.	Coolies.	Mates.
Coolie Gangs.				
2 gangs of 16 with 1 mate, rail carriers (sappers also practiced at this)	—	—	32	2
2 gangs of 1 mate and 14 clip rail carriers (2 spare); sappers also practiced at this	—	—	28	2
4 gangs, material, each 1 mate and 20 coolies (sappers also practiced in unloading and loading up rails)	—	—	80	4
1 gang, 1 mate, and 10 coolies, keeping front trolleys up to the front rail which has been spiked to 3 sleepers (trolleys work up rail by rail)	—	—	10	1
1 N.C.O. superintending loading of trolleys at tip	1	—	—	—
1 N.C.O. ,, unloading of rail trolleys at rail head, and throwing of empty trolleys off the line	1	—	—	—
Total	11	119	249	9

Notes to Plate.

The right rail (*i.e.*, the near leading rail) takes longer to bore and spike than the left one owing to gauging; so a few more men are allowed on it.

The proportion of spikers and augermen is adjusted to work at the same rate. The augermen were afterwards sent ahead of rail head.

Rail throwing is done by turning rails with a tommy bar till they fall off the trolley evenly on the ground; this requires practiced men.

Front fishers do not use wrenchers, only tighten up nuts as far as they can with fingers.

Front "fastenings trolley" is formed by connecting two ordinary trolleys by sleepers; separate divisions are made, on the bogey trolley thus formed, for fish plates, bolts and nuts, bearing plates, and spikes.

This front "fastenings trolley" is replenished from behind. On it are kept spare augers and spare spiking hammers; also wooden pegs for filling up the holes when a spike has to be drawn and another one driven in the same place (spikers should keep some of these in their pockets). Hammer handles are perpetually breaking and the spikers changed their hammers on this first trolley. They were not allowed to take their hammers to the carpenters to be repaired and wait while it was being done. The carpenters were responsible that there was always a good supply of hammers with good handles on the "fastenings trolley."

Supply of Material by Trolleys.

I made arrangements to lay one mile a day, receiving the material by daily trains. There were trolleys enough to carry half a mile or, at a pinch 1,000 yards, of rails. The sleepers, as before noted, were roughly laid, by contract, ahead of the platelaying.

The trolleys were divided into three groups—A, B, and C—each group being loaded with one-sixth of a mile of rails with the proper proportion of fish plates, bolts, spikes and bearing plates. They were pushed out to rail head by all hands as they marched out in the morning.

Plate I. shows the method of working adopted.

As the groups were unloaded, the fastenings were loaded on to the "fastenings trolley," which remained at rail head. Rails were first expended from the front of group C, each trolley being lifted off the line as it was unloaded to make room for the next coming on. Group C then went back to tip. Group B was next expended in the same way and sent back. Group A was next unloaded, carried clear to allow B and C to come up the second time, and then sent back for re-loading. Unloading went on the second time, first from C, then from B; each group being carried clear when unloaded to allow of A coming up. A was then expended, and the three groups were then pushed back to tip in the order C, B, and A. They were there re-loaded for the next day's work. Oiling of trolleys is most important and requires a man told off for this purpose.*

I found it a good plan not to load up in the early morning. The

* Note by Superintendent of Instruction.—When sleepers are not distributed ahead by contract, the front group of trolleys carries sleepers; the next group rails; and so on. The rails and sleepers are in the correct proportion, and each rail trolley carries its own fastenings, plates, etc. The trolleys are unloaded from the front group first, sleepers on both sides of the track; then rails and fastenings. When the sleepers are unloaded and while they are being laid on the formation, each trolley is carried clear of the line by its own gang. The rail trolley, after being pushed forward and unloaded, is also then carried clear.

Sleepers are carried forward by gangs on each side of the track and adjusted. Rails are carried forward and placed in position, each by its own gang.

The second sleeper trolley can be pushed forward before the preceding length is keyed up.

Capt. Maud unloads from the rearmost group of trolleys to begin with. This shortens the lead for the rail carriers of the rearmost group by just the length of rail that is carried on the two foremost groups B and A. The lead for group A is of course increased by the length of rail that is carried by C and B groups; but, on working it out, it will be seen that this method about equalizes the lead for the rail carriers of all three groups.

coolies were cold and stupid at that time and handled the rails clumsily ; whereas pushing the loaded trolley along the line warmed them up for the work of unloading.

By following out a programme like this the work, in theory, should never be checked. In practice, however, many things occur. One train arriving late destroys the continuity of the work altogether.

Rate of Progress.

Towards the end of the platelaying we were getting two trains daily, each with 1,000 yards of material ; and in thirty-one working days 25½ miles were laid. The first eight days' average was 800 yards ; the average of the last eight days was just over 1,600 yards.

The longest length laid in any one day was 2,200 yards. The fastest rate of working was 1,000 yards in two hours.

The difference between this rate and the daily rate was due to the non-arrival of material trains, and to frequent stoppages on account of having to make temporary rail bridges over drainage gaps in the formation.

These bridges varied from 10-foot to 40-foot spans and were bridged as shown in *Fig.* 2.

SPAN 10' (5 Rails each side.)
CROSS SECTION.

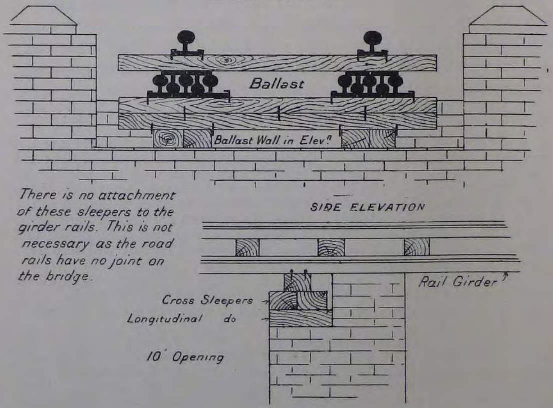


Fig. 2.

The allowance of rails for the girder is, roughly, one (75 lbs.) per foot run of span. Spans over 40 feet were bridged by temporary wooden trestles.

Had it not been for these delays I think we could easily have completed 3,000 yards in an eight hours day.

Remarks.

It would have paid me, even from the point of view of a platelaying contractor, if I had engaged forty coolies to dress the road in front of rail head. The bank had in many places settled unevenly, which caused much delay in placing the sleepers square and in gauging, as well as a large amount of extra work to the preliminary lifting and packing gang.

It is an advantage if ballast can be laid on the formation to a depth of about 4 inches before the platelayers come along. It takes a little longer to get the sleepers square on a ballasted road, but a great amount of labour is saved to the lifting and ballast packing gang by having ballast under the sleepers to begin with. It is a general rule, however, that the road will not be ballasted until the line is laid.

Two men were told off to keep two white sticks about 150 to 200 yards ahead of rail head to give the line for one rail. The N.C.O. in charge of the front party then lined every rail on one side on the line thus given; and, until each rail was correctly placed, the next was not fished up to it. The rail that was thus lined was spiked, and the opposite rail then placed to gauge and spiked also. This first rail is called the "leading rail." Spiking the second sleeper from the front of each rail at once prevented the leading rail from moving when the next rail was fished up to it.

The straightening party coming along behind had seldom to straighten the line more than 2 or 3 inches.

The preliminary lifting and packing party followed close behind. Their business was to see that every sleeper had a fair bearing and to take out bad humps and dips in the line, so that the material train might run over it. At bridges this party had a lot of work, as the rails on the bridges were at rail level and the rails on the road about 8 inches below, so that ramps had to be made.

The platelaying parties on completion of their work handed the line over by the mile to the rear lifting, packing, and straightening gang, who improved it for construction traffic up to 15 miles an hour. This party again handed it over to the permanent way gang in lengths of 3 miles at a time.

PART II.

GENERAL DESCRIPTION OF PLATELAYING.

The system of work herein described will, if followed, ensure rapid platelaying. In any system, the only way to achieve satisfactory results is to make one man do one job and nothing else.

The actual strength and composition of the various parties can soon be determined by experiment.

The sub-division of his company by Capt. Maud, given in Part I., although admirably suited to the particular case he describes, would probably in other cases require some modification.

In the next few pages platelaying is described as seen by one standing on the bare formation in front of rail head and watching the gradual development of the permanent way as the various parties engaged in the work pass, complete their part, and give way to the next party.

Dressing Gang.

The first to appear is a gang of coolies who dress the road, smooth off inequalities caused by uneven settlement, make gentle ramps on either side of bridges up to the level of the bridge girders, and generally prepare the formation for platelaying. Where local ballast has already been spread over the road no dressing is necessary, as ballast spreaders invariably leave a true surface; but the ballast must be sloped gently down to formation on the unballasted portions of the line.

Measuring for Rail Joints.

Next come two men measuring, to see whether in laying the ordinary 30-foot rail a joint will occur on the level crossing or small opening near where we are standing. If such is found to be the case, word is taken back to rail head that so many pairs of 27-foot rails must be laid to bring this joint off the prohibited length. The sleeper layers are also informed of the number of 27-foot rails to be laid, so that sleepers for them may be properly spaced.

Marking Rail Joints on Formation.

The next to come along are the two men who measure and mark on the ground every 30-foot length to show where the rail joint will come. The 30-foot measurement is changed to 27-foot as they approach the level crossing or small opening on which a joint is prohibited.

After these men, a line of country carts loaded with sleepers comes along the road between the foot of the bank and the borrow pits. The two or three rearmost carts come to a standstill, are unloaded, and their sleepers are carried up the bank and placed by the coolie gang, superintended by a N.C.O., as follows:—One unadzed joint sleeper transversely across the bank on each side of the 30-foot (rail joint) mark; the required number of adzed sleepers between each pair of rail joints, placed transversely and roughly spaced. Laying Sleepers.

Looking back from where one is standing, figures can be seen moving towards one; these are the augermen, who follow close on the sleeper-laying gang. The latter, for each train load of material, should finish up about 400 yards ahead of the last rail of the train load that is to be laid. This leaves them with a couple of hours start of the rail-laying gang when the next train load of material arrives. Auger Party.

The contract with the sleeper carters is usually for an average mile haul from the material train. It is a constant source of complaint on their part that their haul exceeds the mile. If it does in one case, it is probably under the average in another.

One next notices that the man whom one saw previously measuring the lengths for joints is now employed in laying off lengths equal to half the gauge of the line right or left of, and at angles to, the 1,000-foot centre line pegs which are fixed in mid-formation. At these distances, right or left of the centre line pegs, he is fixing in the ground small vertical white staves; these mark the centre of the right or left rail, as the case may be. Similar staves are fixed right or left of the 1,000-foot pegs behind us, and between these staves and in their line others are interpolated. The line of the "leading rail" is thus laid out on the ground for the platelayers. "Leading Rail.

The augermen are boring holes for the spikes in the right end of the sleepers, the left ends having been previously bored. This party is preceded by a couple of men who carry a "firman," *i.e.*, a board at one end of which is a peg and at the other end two holes. Augermen.

The peg is fitted into one of the ready bored holes in one end of the sleeper; the firman is placed over the sleeper, square; and, with a punch through the holes in the firman, two distinct marks are made in the other end of the sleeper. The augerman, coming on with a ½-inch auger, bores his holes in the places indicated by these punch marks. As each man finishes boring, he moves forward and tackles the next unbored sleeper ahead.

The holes must be bored completely through the sleeper; and they are tested here and there by the foreman of the gang (a N.C.O. in military platelaying).

Boys distributing Fastenings.

After the augermen come small boys distributing fastenings. They place spikes across the end of each sleeper and, for a joint sleeper, four spikes and a bearing plate. At each joint two fish plates and four bolts are also left.

Rail Carriers.

The rail carriers are now coming along, fifteen of them to a 30-foot rail weighing 75 lbs.

On arriving clear of the last rail laid, they halt; those with their outer shoulders under the rail change sides, and the whole gang stand ready on the outer side of the rail to throw it at the word of the end man.

Possibly the next rail that comes along may be carried by means of chains and clips by a party of twelve to fourteen men. This system is not so good as the other, as the party takes up too much room and there is always some delay in fixing the chains and clips. One advantage of it, however, is that untrained men can work at it; whereas, for shoulder carrying, the gang employed need to know each other and want a certain amount of practice.

Expansion Piece.

As soon as the rail is thrown one man places an expansion piece against the end of the last rail laid, and the new rail is then butted up tight against this by five men. The rail is then lined on the white staff ahead; this is most important, as it saves a lot of straightening out afterwards.

Fishers.

As soon as the rail is left by the front party the first pair of "fishers" fish up the joint. One man (the outer), who has put two bolts through the two inner holes of a fish plate, passes the two bolt ends through the two end holes of the two rails to be fished. If necessary, a coolie with a bar raises one rail to bring both to the same level. This difference in level between the ends of two adjacent rails is caused by uneven thickness of sleepers or by unevenness in the road.

The other "fisher" (the inner man) slips the fish plate he carries on to the two bolt ends and puts on the nuts, *running them up to a bearing with his fingers only*.

The expansion pieces are left between rail ends for the present, and the two fishers then double to the next joint, to repeat the process there. Another rail-carrying party and another pair of fishers are of course doing the same work on the other rail, the only difference being that whereas the "leading rail" is lined on the staff ahead, the other rail is simply laid as straight as possible to gauge from the "leading rail." The man in charge of the first party looks periodically to the squareness of the opposite joint, and, if one rail has a lead, he corrects this by using thicker or thinner expansion pieces, or as described in Part III. "General Notes."

Work on a Curve.

On approaching a curve special men are told off to cut rails for the inner rail of the curve. The bolt holes at the end of a rail are 6 inches apart and the end hole is 6 inches from the end of the rail, so that if 6 inches exactly is cut off the rail, the second bolt hole comes 6 inches from end of the cut rail and can therefore be used for fishing. On the curve, when the man in charge of the first party sees that the inner rail has 3 inches lead, he orders one of the cut rails to be placed on the inner side. This gives the outer rail a 3-inch lead, and thus the lead of either rail is never more than 3 inches. A following party drill the second bolt hole in the end of the cut rail and double fish the joint. (*Instructions as to how a rail should be cut will be found in Part III., "General Notes"*).

On very flat curves in the main line no bending of rails is necessary; the slight amount of curve required can usually be given by the straightening party with their bars. On curves, centre pegs will be at distances of from 50 to 500 feet, depending on the steepness of the curve. Aligning staves, for the leading rail, are not used.

Marking Places where Sleepers cross Rail.

As soon as the rail has been placed in position, and while it is being fished, a man with a piece of chalk and a measuring rod marks where each sleeper will cross the rails, so there shall be no mistake about getting the sleepers square. On a curve, or if the rails vary slightly in length, only the leading rail should be marked; the sleepers must be squared by eye by the spikers who, on a curve, should place the sleepers radial from the centre of the curve. The man entrusted with this job should be intelligent as, when he is marking a cut rail or one not exactly 30 feet long, he will have to divide up the excess or deficit of the rail length among all the spaces marked; unless this is done, very bad spacing is the result.

Tightening Up and Spiking.

We have now seen the rails aligned, marked, and partly fished up; and the rail parties have gone on to the next pair of rails. A wrench man now arrives and proceeds to tighten up the two fish bolts; and at the same time the first spiking party (two sets, each consisting of two spikers and a lever man, one set on each side) proceed to spike the rail to, say, the second, fifth, and eighth sleepers.

The spikers for the leading rail are a little in advance of the other set; they finish first and move one rail ahead. Their way of working is very simple; the rail is placed between the auger holes previously bored in the sleeper, and the sleeper is then squared and the spike driven home.

Material Trolleys.

Spiking to three sleepers will allow the material trolleys to run without being derailed. These now come along; first the smaller one, a bogey formed of two trolleys, loaded up with fittings in separate divisions and also with a small proportion of spare auger and hammer handles.

The rail trolleys come next, the whole lot moving up rail by rail so as to reduce the lead and keeping as near rail head as possible.

Carrying Rails.

One of the trolleys halts. A man with a tommy bar prizes off a rail, which falls flat on the ground and is immediately seized and carried off by the rail-carrying party with their chains and clips. On the other side of the trolley another rail is prized outwards, clear of the platform, until it rests on the projecting ends of the two sleepers laid transversely across the trolley; the rail-carrying party on this side get their shoulders under this rail, lift it off the sleepers, and march off with it.

2nd Fishing Party.

Close behind the trolleys come the fishers, and with them men who place bearing plates under the rails on the joint sleepers. The outer edges of the joint sleepers come just under the ends of the fish plates, thus the space between joint sleepers is less than that between others. In spite of that and in spite of the fact that the fish bolts are tightly nutted up, these joint sleepers get the greatest strain on account of the incessant bending of the rail ends when traffic is passing. Bearing plates, by increasing the bearing surface of the rail, save the sleeper underneath.

2nd Spiking Party.

The second gangs of spikers now come along each line of rail and finish spiking the rails to those sleepers left untouched by the advance spiking gangs.

Straightening Party. Preliminary Packing Party.

The straightening party come behind the spiking gangs to straighten out the line. This party is again followed by a preliminary packing party, who pack under each sleeper until it has a sufficiently good bearing to allow the material train to run. This packing is done with earth unless ballast has been previously spread over the formation. No digging up of the formation should be allowed, the earth required should be taken from borrow pits.

Material Trains.

When the material train arrives near rail head all material should be checked with the way bill sent by the storekeeper. Material is unloaded in the way most convenient for re-loading it on the material trolleys. A good deal of labour may be saved for the future if some thought is given to the unloading of the material trains.

The sleeper trucks should if possible be detached where the line is in bank, so that the sleepers may be unloaded clear of the permanent way. Rail trucks should be allowed space for the rails to be unloaded in three different lots, each clear of the other.

Each mile of road, as it is completed up to and including preliminary packing, is handed over to the rear packing gang who, in turn, hand it over in 3-mile lengths to a permanent way gang.

PART III.

GENERAL NOTES.

SUPPLY AND LOADING OF MATERIALS.

These notes contain a good deal that may appear trifling; but, in military platelaying particularly, speed is the great desideratum, while organization and attention to detail are the two principal factors necessary to ensure rapid work.

Material Train.

The maximum load that can be drawn by a main-line engine over an earth-ballasted line at a maximum speed of 15 miles per hour, on the flat, is 1 mile of material, *i.e.* :—

2,000 sleepers (1,836 only are required, the balance is spare).
360 rails, 30 feet long, 75 lbs. (only 352 required).
176 bundles fish plates, 4 fish plates to a bundle.
704 bearing plates.
9,500 spikes (the actual number required is as follows :—

$$\left.\begin{array}{l}\text{9 sleepers each 2 spikes}\\ \text{2 joint sleepers each 4 spikes}\end{array}\right\} 26 \times 2 = 52 \text{ per pair of rails.}$$

$52 \times 176 = 9{,}152$ spikes per mile).

1,600 bolts and nuts (actual number required $= 8 \times 176 = 1{,}408$).

The stores should be loaded, rails in front, sleepers behind, and small material on a separate truck, not thrown on top of rail truck.

Rails.

Rails are usually loaded either on regular rail trucks, which are very convenient, or on bogie trucks.

The truck platform of a rail truck is 18 feet long, the sides only 6 inches high. The rails lie across transverse beams fixed to the truck and should be arranged so that they rest on a different level on each alternate truck in order that rails on adjoining trucks may overlap. They are laid evenly, flat foot underneath, the second layer resting on the heads of each two rails of the layer underneath. This ensures easy unloading.

Bogie trucks are about 30-feet long with ends and sides 2 feet 6 inches high; ends can usually be let down. Rails are difficult to unload off these trucks unless loaded carefully.

When bogies are coupled in a construction train "dummy trucks" should be coupled on each side of them to allow room for the rail ends.

Rail trucks are provided with four chains, two on each side, each opposite pair meeting in the middle of the truck and coupled together with a screw shakle. Unloading rails is done by about 12 to 18 men under a mate ; each rail should be unloaded separately, and thrown so as to fall flat and fairly parallel with the line ; if it does not fall so, it causes difficulty and delay in the rail carrying. A man with a lever should be below to straighten the pile of rails.

With very low-sided rail trucks the unloading party need only be about four men with bars, as no lifting is required.

Sleepers are loaded on ordinary goods trucks at the rate of about 100 10-foot sleepers per truck. They should be unloaded where possible from an embankment, so that they can be thrown well clear of the rails. Sleepers.

In all indents on the storekeeper for material it is most necessary to specify exactly what is required. Indents for one mile or half a mile, etc., of material is not sufficient. If the quantity required of each article is not stated mistakes are sure to occur, and these mean delay. On receipt, a copy of the way bill should be compared with the original indent before the material is checked. Avoid accumulating a lot of surplus material at rail head and avoid also leaving fastenings, etc., strewn along the line ; rails rejected at rail head may be left behind, but nothing else. Supply of Material.

It is always advisable to keep a rail head ledger for all material and platelaying tools taken over. This ledger should contain columns for the number of the invoice on which the tools, etc , were received, for the date of arrival of construction trains at rail head with the tools in question, and for the number of the train on that date. An immense amount of confusion will be saved by this simple means.

If the work is being done on contract, an arrangement should be entered into with the railway authorities as regards compensation for the non-arrival or irregular supply of material. The actual supply guaranteed by the railway should always be specified.

Preliminary Work.

Before platelaying is actually begun there is a certain amount of preliminary work which can be undertaken.

1. *Boring sleepers* for the "firman" mentioned in Part II. I would not recommend all four holes being bored, as even with a template mistakes are liable to occur.

2. *Running down nuts* of the fish bolts is very important. A nut that has been previously run down can be screwed up in half a minute, against five or six minutes which it takes to screw up a stiff nut. If it is not possible to run down all the nuts, those that are used by the fishing party can at any rate be seen to.

3. *Bring the formation up to an even level* before spacing the sleepers already spoken of in Part II.

4. *Overhaul* all the tools and plant. Weak hammer handles should be rejected, and the whole of the working kit should be overlooked to save delay when work has once begun.

5. *Practice the men* in cutting rails, bending rails, spiking, etc., if you have any spare time. It is wonderful how a little practice improves the rate of working.

To cut a short length off the end of rail.—The rail is nicked around with a cold chisel at the place at which it is to be cut, the sides of the foot of the rail being cut deeper than the other part. A "Jim Crow" is then put on. If the length to be cut is so small that the arm of the "Jim Crow" comes outside the rail, proceed as follows:—Get a short piece of rail end with two fish plates loosely bolted on through the two middle bolt holes of the fish plate. This rail is bolted up against the end to be cut, the two fish-plate ends coming on either side of this with their ends just clear of the nick around the rail, leaving room for the "Jim Crow" spindle. By nutting up the two fish-plate bolts, the plates act as a vice holding the end of the other rail and giving a bearing for the outside arm of the "Jim Crow." As the "Jim Crow" is being screwed up tap the rail between its arm with a sledge. Cool the rail with water before commencing to screw up the "Jim Crow," and a clean fracture will result. But if the rail is not watered it will bend before breaking.

Lead, Linking Up, Spiking.

In all platelaying a maximum is fixed for the lead allowed to a right over a left rail or *vice versâ*, *i.e.*, the rail joint of two right-hand rails is never allowed to be more than the fixed distance ahead of that of two left rails. A man must be specially instructed to watch and measure the lead and to correct it, *e.g.*:—Suppose the maximum lead allowed is $1\frac{11}{16}$ inches; lead is allowed to work up to this amount on one side, and then a rail $3\frac{3}{8}$ inches short of the normal length is put in on this side, which transfers the lead of $1\frac{11}{16}$ inches to the opposite side.

In order to measure lead use a T-square, the stalk of which is the width of the maximum lead admissible, in the example given above $1\frac{11}{16}$ inches. Lay this across the rails, and when the end of one rail coincides with the leading edge of the stalk and the end of the other rail with the rear end of it the maximum admissible lead has been reached and a cut rail length is required on the side of the leading rail (the "lead" of a rail should not be confused with the "lead" of a crossing). In using the T-square it should be placed across rails that have either been partially spiked or adjusted for spiking, so as to make sure, in correcting the lead, that the rails are parallel.

The man watching the "lead" should never allow the 1st Fishing Party to get more than two or three rail lengths ahead, otherwise it may mean undoing joints to get a length out. Lead is by no means a constantly increasing quantity, owing to rails varying in length, which they do up to sometimes $\frac{3}{4}$ of an inch.

Fishing up.—Particular care should be taken that the 1st Fishing Party do not touch a rail until augers are clear of the sleepers on which it rests. Otherwise the auger men will shift the rail to get at their work and, the joint being partially fished up, bent plates, crooked line, and much trouble and delay will ensue.

It is best not to take out expansion pieces until the 2nd Fishing Gang come along.

In spiking, if a spike be driven askew it should be taken out, the hole re-plugged, and the spike re-driven. The last stroke on the head of the spike should be a light one, otherwise the head of the spike may snap off.

Expansion Pieces, Gauges, Packing and Straightening.

Spaces for rails to expand are left between every two rails on each side. These spaces should be such that, with the rails at maximum temperature, their ends should be just clear of each other. Leaving too much space means that trains do not run smoothly over the road; if too little space is left, the rails will buckle.

It is obvious that the temperature of a rail is not always the same during platelaying; the time of day makes considerable difference. Expansion pieces of different thicknesses should therefore be used for varying temperatures. In practice, two sets will probably suffice; the thicker set for use between 7 a.m. and 10.30 a.m., the thinner set for use from 10.30 a.m. up to 4.30 p.m. The difference in thickness of the two sets for any weight and length of rail can easily be found by experiment. They should be of such a shape that they will not be caught by the fish plates nor be easily knocked out by the preliminary linking-up gang.

Gauges get easily bent and should be periodically tested for accuracy. Slack gauge $\frac{1}{8}$ inch is usually allowed. When dropped over the rails the gauge should just shake and when moved sideways to the line there should be a little lateral play both ways. Natives are rather fond of putting the gauge at an angle to make tight gauge appear correct.

Generally an extra $\frac{1}{8}$-inch slack gauge is allowed on curves. Special curve gauges are necessary; they should be painted red and should be issued as the platelaying parties come on to the curve, and taken away when the end of the curve is reached.

Packing and Straightening.—The rail joints are brought up to level by a board on edge which is placed across the joint where the rails are the proper height; other boards are placed on the next joints ahead and the top edges are brought into the horizontal plane by packing up the sleepers. On curves it is sufficient to straighten the line to a series of straight chords, leaving the ultimate straightening to be done by the rear packing and straightening party. If the line is very badly out, do not bring any particular part into immediate alignment. Do it partially at first and complete it after, otherwise there is a risk of permanently bending the fish plates. The straightening is done by bar men working in pairs from the inside of the rail. Straightening the length is completed before packing is begun. The men, armed with beaters, work in pairs diagonally opposite each other, at each sleeper, beginning with the centre one of each rail length. On curves the correct amount of super-elevation is given to the outer rail.

Girder Erection.—To get rail head across a narrow gap, make first of all a makeshift bridge of sleeper stacks. Material can then be crossed, so that the work of platelaying can go ahead on the far side.

When unlinking to put in the girder, if the temperature is high or low, the rails will be found to have expanded or contracted, so that it may be difficult to link them up again. In order to avoid this difficulty loosen up four or five joints on each side of the gap, so that the expansion or contraction may be divided up among several joints.

Points and Crossings (Military Platelaying).

The notes herein contained are only intended as hints with regard to the actual work of putting in points and crossings.

The whole subject is fully treated in the book by W. H. Cole mentioned in the preface.

1. Take a copy of the dimensions given in Cole's book for each set of points and crossings which you have to lay out. Make each N.C.O. draw out a rough sketch of a set of points and crossings, with the dimensions. Explain fully to them the significance and names of the various parts.

Points and crossings are known by their number, which is the co-tangent of the angle of their intersection. Nos. 12 are generally used in main line loops, Nos. 8 for goods sidings.

2. It is well to try and induce base-storekeepers to send the fittings of sets of points and crossings in the boxes in which they arrive, unbroken. Once opened a very careful watch should be kept on the boxes, as there are no spare fittings and one set can only be made up at the expense of another.

3. Before proceeding to put in points and crossings, first get a plan of the station yard and reduce the chainage on the plan to a zero at some convenient point on the main line, say the centre of the passenger platform.

Mark off *on the flange* of the main line rails where the turn-outs from the main line are to come, and also the points at right angles to which other points and crossings or dead ends will come on other parallel lines. Get this accurately and permanently done.

4. Fix centre pegs for the lines parallel to the main line, *allowing accurately* for the clearance between lines; ascertain the irreducible minimum length of loops and sidings with dead ends, etc. It is not always absolutely necessary to keep exactly to the chainage given in the plan; if you can save cutting a rail by altering slightly the length of a loop or siding, or by increasing it, do so. The only point to be careful about is that your length does not come under that laid down by regulation. For instance, platform loops from the main line have a fixed minimum limit on the straight, and a Government inspector will move a set of points 1 foot to bring the straight up to this minimum length.

A double section of a Bengal Sapper Company is a convenient unit for putting in a set of points and crossings, *i.e.*, 40 men, including N.C.O.'s.

5. Rails for intermediate portions between the point and the crossing should not be cut until the gap in which the cut rail is to be placed can be actually measured ; otherwise mistakes are liable to occur and rails may be wasted.

Joints cannot be squared between points and crossings in a "turn out" or between crossing and crossing—the "straight" of a "cross over"—but the second joints from the point or crossing on the straight line should be squared, rails being cut for this.

6. Gauge should be rather tight just in front of points.

7. The curve of the line between the point and the crossing should be easier near the point and slightly sharper near the crossing. This curve is adjusted, usually by eye.

8. The centre of guard rails should be exactly opposite the gap between the nose of crossing and the junction of the two rails opposite it which they protect. As points and crossings must be very carefully laid originally, it will never be necessary to alter them, and it will not be necessary to make the curved line from the point and the crossing so that it may be moved independent of the straight line.

To do this entails a lot of work. Each sleeper has to be cut where the rails to which it is not spiked pass over it, so that no rail bears on any but its own sleeper, *i.e.*, the one to which it is spiked. This gives each line its own sleepers and places the sleeper of the straight line absolutely at right angles to its rails, while those of the curved line are interpolated, as nearly as possible, normal to the curve.

9. The crossing rests upon and is bolted down to four or five long sleepers according to its number (*i.e.* :—cot. of angle of intersection). These sleepers also take the two outer rails, thus making the "turn out" absolutely rigid. It is a fairly common practice among platelayers to ram these holding-down bolts in, screw thread downward, and to fix no nuts underneath, as this saves trouble. This practice is of course absolutely indefensible. The best method of fixing the crossing to its sleepers is to make a sleeper platform, place the long crossing sleepers over it at their proper intervals, then place the crossing on the sleepers and bore the latter through the holes in the crossing bed-plates. Put bolts through from underneath and nut up on top. The crossing thus fixed can be then placed in position.

NOTE.—*These papers were originally published at Roorkhee as an "Instructional Circular" of the Bengal Sappers and Miners.*—[ED.].

PLATE I.

WITH RAILS AN K 1 MILE DAILY).

rried by each group an be increased.		Fastenings trolley.	
	IV.	VIII.	IX.
begins. loaded nded t of which mpty ip.	Expend from front of Group B ; load Group C at tip. B when empty sent back to tip.	Expend from front of Group A.	All unloaded 2nd time.
If there are two material trains daily, the first now arrives near rail head.	A B B C *Partially loaded*	A B C	A B C *Run back to Tip*

PAPER VII.

HARBOUR WORKS AND DOCK CONSTRUCTION.

By W. W. Squire, Esq., M.I.C.E.

(*Lecture delivered at the School of Military Engineering, Chatham, on December* 18*th*, 1902).

INDEX.

ERRATA.

Paper VII.—Page 128, line 5 from bottom. In *Fig.* I., *Plate* III., *for* "Section of Modern Dock" *read* "Section of Modern Vessel in old form of Dock."

Page 134, line 10. *Omit* sentence from "A single" to "*Plate* XX."

Page 137, line 3 from bottom. *For* "*Fig.* 3" *read* "*Fig.* 2."

In *Plate* III., *Fig.* II., the diagonal shading of task (3) should cease at the inner vertical faces of task (2), and the horizontal shading of task (2) should be continued to the inner vertical faces thereof.

PAPER VII.

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INDEX.

INTRODUCTION.

You already have so much valuable information on this subject in the lectures on Marine Engineering delivered here by the late Mr. J. B. Redman in 1875—1876, in the published descriptions of executed works, and in the books specially devoted to this branch of Engineering, that I find it difficult to bring before you anything that will add to your knowledge. But as the subject is of some importance at the present time and as it has been my business to be associated with harbour and dock works in this country and in India, I propose to invite your attention to a few points which you may perhaps find of interest, and ask your indulgence if they should be already familiar to you.

Harbours may be considered as places where vessels take shelter from the violence of the sea and where landing and embarking, loading and unloading, and repairs may be carried on in safety. *Docks* may be considered as accessories for more conveniently carrying out the purposes for which vessels resort to the shelter of a harbour.

From time to time, as vessels have increased in size, and trade and travel have developed, the harbours and docks of our own and other countries have been added to, improved and enlarged. But at present there seems to be in progress a development in the size and speed of vessels, in trade, and in the movement of people over sea, greater than anything of the kind in the past. To meet this new development the accommodation in some ports is insufficient, and in many parts of the world there is still a total absence of harbours and docks on long stretches of coast. I need hardly say more to show the importance of modern harbour and dock accommodation.

HARBOUR WORKS.

Harbour Works include :—

Natural Harbours.

(1). The *adaptation* and *improvement of natural harbours* where shelter has been provided, either by the configuration of the coast line, or by the position of an island, or in great estuaries.

Harbours partially protected by nature.

(2). The provision of *protection from certain quarters* where nature has provided partial shelter only.

Artificial Harbours.

(3). The construction of purely artificial shelter on exposed coasts, where refuge in emergency is required both for trading vessels and ships of war.

Minor Works.

In addition to the great constructive works which such undertakings involve, we may include the work of surveying, lighting, and buoying the approaches to a harbour; the removal or marking of rocks and shoals; and the removal of accumulations of silt from the channels and from the landing places and docks.

The provision of landing places, of means for landing and embarking passengers, cargo, cattle, troops, warlike stores and materials, and of warehouses for the reception and storage of merchandise, may or may not necessitate the addition of wet docks to the equipment of a harbour; but for the purpose of effecting repairs to ships some form of dry dock is essential. Docks.

For the purpose of providing or improving the shelter, which is the first essential feature in a harbour, breakwaters and piers connected with the land, or breakwaters detached from the land, are built; and, except in the case of detached breakwaters, the same structure may sometimes fulfil the requirements of shelter as well as those of communicating with the shore. Breakwaters.

Some breakwaters are formed of rubble stone or blocks of concrete thrown into mounds; others are built with upright sides, either of masonry, concrete or timber, or of timber framing filled with stones. The violence of the sea is resisted by the mass of work in some cases; in others the waves are spent on long slopes, or broken by level benches, or berms, alternating with slopes.

Works for Protection and Communication with the Shore.

Perhaps the most important harbour works at present under construction in this country are those for the great Admiralty Harbour at Dover. An area of 610 acres is to be enclosed by two piers and a detached breakwater.

On the west side the Admiralty pier will be extended about 2,000 feet; on the south there will be a detached breakwater 4,200 feet in length; and on the east side there will be another pier 3,320 feet in length. There will be an entrance 800 feet wide at the west end of the breakwater, and another 600 feet wide at the east end. At present about half the Admiralty pier and half the east pier have been completed; and the construction of the breakwater is about to begin. The works are estimated to cost about $3\frac{1}{2}$ millions, and are being carried out under Sir Henry Pilkington, K.C.B., as chief engineer. Within the Admiralty Harbour the Dover Harbour Board are constructing a commercial harbour, the east pier of which has been completed. The south pier and the proposed pier in the centre of the harbour are not yet begun. Dover.

Heysham.

A harbour of a different type is that under construction by the Midland Railway at Heysham. Two breakwaters are being built out from the land, enclosing an area of about 100 acres. The breakwaters converge towards their extremities, leaving an entrance 300 feet wide Within the breakwaters there is a tidal basin, 1,700 feet long by 700 feet wide; a wet dock, timber pond, and dry dock will also be constructed. The dock will be entered through a lock; but the tidal basin is open to vessels at all states of the tide, and the south wall is provided with wooden stages at three different levels for the landing and embarkation of passengers and cattle.

In both these harbours the protective works are of concrete founded on the hard bottom.

Fishguard.

An example of the extension of natural protection is shown by the harbour works of the Great Western Railway at Fishguard, where a breakwater 2,000 feet in length is in course of construction. Here, owing to the soft character of the foundations far out, a rubble mound composed of blocks of stone is being tipped. This will be surmounted with large concrete blocks. The tipping of the rubble mound is carried on at the rate of 1,200 to 1,500 tons per day in a depth of 40 feet of water at L.W.O.S.T., the progress forward per day being about 2 feet.

Osatka (Japan).

In tipping such a mound in soft mud the sinkage is sometimes very great. The breakwater at the Osatka Harbour works, Japan, is an illustration. Here the mud has been bored to a depth of 198 feet, and the sections are said to represent the actual finished work. Though many famous breakwaters have been founded on rubble mounds, such foundations require very careful consideration of all the circumstances that may affect their stability.

Mouth of Tyne.

The north pier at the mouth of the Tyne was founded on rubble tipped on sand overlaying hard shale; and, though the foundations were taken down 27 feet below L.W. level, it was found that the disturbing action of waves extend to a greater depth than was expected. The sea eventually undermined and breached the pier towards the outer end, and it is now under re-construction for a length of 1,500 feet. The foundation of the new portion is being taken down to the hard shale without a rubble mound. The construction is of concrete blocks throughout.

Concrete in large bags containing from 12 to 50 and even 100 tons weight, deposited in place by barges provided with hopper doors, has also been used for the foundation of piers and breakwaters.

In studying the details of works great variety will be found in the methods of construction, from the blocks of 350 tons used by Mr. Storey on the Liffey in Dublin to liquid concrete deposited in frames. Much skill has been shown also in devising joints to prevent dislocation and to admit of settlement without distortion.

An example of a timber breakwater (*Plate* I.) is in progress at Ching Wang Tao, in North China. Here the breakwater is being constructed of Jarrah timber piles, filled in between with rubble stones up to L.W.O.S.T. Ching Wang Tao (China).

WORKS FOR THE COMMUNICATION WITH THE SHORE ONLY.

At Algoa Bay, in South Africa, the harbour works are mainly for the purpose of communicating with the shore. Here heavy iron jetties (*Plate* II.) have been erected on piles screwed through the sand to a hard foundation. They project from the shore to a considerable distance into the sea; and, being provided with cranes and railway sidings, form spacious and convenient wharves. Algoa Bay (S. Africa).

Another type of harbour work for communication between ships and the shore is the great landing stage at Liverpool upwards of 2,000 feet long and 80 feet wide. As the stage is floating, it is immaterial (provided the depth of water is sufficient) at what state of the tide vessels come alongside, the height of the deck above water remaining constant. The deck of the stage is carried on girders, which rest on a number of pontoons. It is moored by chains and booms and is connected with the shore by hinged bridges. Liverpool.

On shore, parallel with the landing stage, there is a railway station and rooms for customs examination of baggage. Conveyors or travelling platforms carry the baggage from the landing stage to the station.

For the purpose of landing or embarking, or loading and unloading cargo, the range of tide and the stillness of the water are important in determining whether it is necessary to provide docks or not. With a moderate range of tide and fairly still water, open piers or jetties and wharves within the harbour are often sufficient. Such structures are built of masonry, concrete, steel or timber, or a combination of these materials. Jetties and piers are of limited width; but with regard to equipment and accommodation for cargo, open wharves are similar to wharves in docks.

MINOR WORKS.

In the lighting of harbour approaches lighthouses of the first order may be necessary, as well as less important lights. Electricity, gas, and oil are used as illuminants; and great improvements have been made of late in obtaining the most efficient light and in reducing the amount of attention required. Buoys and beacons are provided with lights that will burn without attention for a week or 10 days at a time. Rocks and shoals, that it is not necessary to remove, may be marked by the erection upon them of beacons built of solid masonry or of open framing of steel; and they may be illuminated at night, or the danger may be covered, by a red ray projected over it from a lighthouse at a distance. The deepening or removal of shoals may be effected by dredging with buckets, grabs, or pumps; rocks may be bored and blasted, or broken by heavy blows from rock breakers, ready for removal by dredgers; or, in favourable circumstances, rock may be dredged by "ripping claws" alternating with buckets.

DOCK WORKS.

Wet Docks.

For repairing vessels under water some form of dry dock is in any case a necessity. For the other purposes to which I have referred, some form of enclosure may be necessary where vessels may lie alongside a wharf with greater security and work with greater convenience than in an open harbour; such enclosures are generally termed wet docks.

Past and Present Requirements

Particulars of the earlier docks in this country are given by Mr. J. B. Redman in the lectures to which I have already referred. At the time those lectures were delivered, a great development in shipbuilding was taking place and new docks were being built at many of the principal ports. Some of the works, which were then in course of construction, have become inadequate to meet the further development now in progress; and even greater efforts than he referred to have become necessary in order to meet the new conditions which have arisen.

The largest passenger steamer afloat in 1878 was 490 feet in length; and, in speaking at the Institution of Civil Engineers in that year, Sir John Coode considered that a dock for ocean-going steamers ought not to be less than 600 feet wide. This dimension, however, would have been hardly enough to allow for turning the *City of Rome*, 560 feet long, which was built three years later. In 1893 the *Campania* and *Lucania* were built, each 601 feet in length; and in 1889 the *Oceanic*, 685 feet in length.

The present century began with the launch of the *Celtic*, 700 feet in length; and now we have vessels proposed for the Cunard Company, 750 feet in length. With regard to the increase in tonnage of vessels it is stated that until 1895 there were no British cargo vessels over 6,500 tons. In Lloyds' register for this year (1902) there are 70 vessels of over 10,000 tons, half of which are British. It may be said that these are exceptional vessels, but the tendency is to build large vessels; and, excluding the very largest class, modern docks must provide at least for cargo vessels carrying 12,000 tons weight or 20,000 tons measurement (allowing 40 cubic feet to the ton).

The growth in the size and the speed of vessels has a wider effect than merely requiring enlarged dock space. It is altering the conditions under which the land and sea transport of merchandise is carried on. These huge vessels must be loaded and discharged in quicker time than smaller craft. The smaller vessels in former days might remain in port for a week or ten days, but owners cannot afford to keep such costly property as a large modern vessel idle in port; cargoes must consequently be handled with a rapidity that would have been considered impossible a few years ago.

Passenger vessels again require facilities for the rapid embarkation and landing of passengers, mails and baggage, the great American liners at Liverpool completing the operation in half an hour.

A modern dock must therefore be so designed that a vessel on arrival in port can proceed to her berth, discharge and load cargo, land and embark passengers and mails, and proceed to sea again as quickly and safely as possible. In ports where the range of tide is favourable (as at Southampton, Glasgow, and some of the Continental ports), the wet docks are open basins which vessels can enter and leave at all states of the tide. But where it is necessary to limit the fluctuation of water level for convenience of working, the entrance to the dock must be closed and the water kept in by gates or caissons. In such cases, to avoid waiting till near high water, locks are often provided at the entrance; or else half tide or vestibule docks which practically fulfil the same function. The exact shape of a dock and the arrangements of the berths may be governed both by the available site, the means of access from the land to the wharves, and the kind of trade to be done. It is desirable, and in some cases essential, that, in order to avoid turning a vessel in the stream, there should be sufficient space within the dock for her to be swung round ready to go to sea again. For vessels of the class indicated above, a space of at least 1,000 square feet would be required. The wharves may be arranged either in as long and unbroken lengths as practicable or broken up into short lengths by a number of jetties or moles. Generally speaking, if sufficiently good access from the land can be obtained, the extended wharves may be considered to be the more economical in quay space, as no short lengths between vessels need be wasted; whereas, if the wharves are broken up into a number of short berths by jetties, they are unlikely to be always occupied by vessels of the same length as the wharf. On the other hand the jetty system offers many advantages where berths are allotted permanently to a particular company or for a particular kind of trade.

Entrances.

The entrance to a dock must be so designed that a vessel can pass through it quickly and safely. The width of entrances closed by gates is now seldom less than 85 to 100 feet for modern liners. The new dock entrances at Liverpool are 100 feet wide, whereas less than thirty years ago 65 feet was considered ample. It may be remarked that, both at Birkenhead and Liverpool, entrances had previously been built 100 feet wide to provide for the extreme dimensions expected to be attained by paddle steamers. The depth of sill is governed by the draft of vessels, having regard to local conditions of tide, trade and other considerations. In addition to increased length and beam, a further development in the dimensions of vessels is in progress in the direction of increased draft. The maximum draft forty or fifty years ago was 24½ feet. For the new Cunarders a depth of 32½ feet is to be provided on the Clyde; and a vessel (the *Silvertop*), launched on the Tyne at the beginning of December, is said to have a draft of 35 feet. Much, however, depends on the period of tide at which the gates are intended to be opened. If a lock or vestibule dock is to be used at half tide, the sill must be deeper than when docking is only to be done near high water. At Avonmouth the sills are to be deep enough to give 36 feet of water at O.N.T. In docking vessels of the modern rectangular section, especially if fitted with bilge keels or rolling chocks, through the older entrances with battering sides and curved inverts, considerable allowance must be made (*Plate* III., *Fig.* 1); consequently, in modern entrances, the sides are built vertical and the inverts as flat as possible. The direction of the entrance should be considered with regard to the state and direction of the current off the entrance at the time when vessels are likely to dock. This is usually from half flood to about high water. It is of advantage to point the entrance so that a vessel may approach it with her head to the stream unless protection can be given by piers which will practically enable her to enter in slack water. In some cases there is a downset inshore while the flood is still running up, and careful study of local conditions is therefore necessary before deciding the angle of the entrance in a particular case. If the current across the entrance is strong, the protection of a pier is desirable in order to avoid the danger of a vessel about to enter the dock being swept round at right angles to the entrance. It may then be difficult or even impossible to right her without a tug, and the delay involved may result in losing the tide. A hitch in passing a vessel of 500 or 600 feet in length through the entrance, with a strong cross current running, may cause the vessel when partly in and partly out to be so jambed as to cause serious danger. The operation of docking a long vessel is always an anxious one for all concerned, and slack water and a clear run in are important points to be kept in view in designing the entrances. All knuckles should be avoided both to save straining the ship and to reduce warping as much as possible. At Avonmouth protecting piers are provided on both sides of the entrance ; and a vessel coming up on the flood is carried naturally alongside the pier, in a position ready to enter the dock without turning through any angle of consequence.

Locks.

In closed docks the entrance can only be opened when the water on both sides of the gates or caissons is level. On rising tides the gates could be opened before high water as soon as the tide reaches the level of the water in the dock, but this may leave too short a time to pass all the traffic in and out before the gates are closed again. On falling tides the tide might possibly not reach the dock level at all. If the dock is provided with only a single pair of gates, it is therefore necessary to run down the water in the whole dock to meet the tide. This can only be done to a limited extent if there are deep draught vessels in dock ; and, even if water can be spared, it is sometimes desirable in muddy estuaries to admit as little tidal water as possible on account of the silt that would be deposited in the dock. To obviate these difficulties recourse is had to half tide docks communicating with a group of docks, or to locks communicating with single docks. The result is the same in both cases. The water in the half tide dock or lock can be run down to meet the tide, the water level in the docks being kept up. In the case of half tide or vestibule docks as at Liverpool, after all the vessels have been passed in or out, the outer gates are closed and the water in all the docks of the group is brought to one level. In the case of locks the operation is the same as in a canal. In either case some water is lost ; and, unless there is a natural supply from a river or stream to make good the loss, it must be made up by pumping during neap tides. When the springs are high enough the loss can, if desired, be made up by direct admission of tidal water.

Locks for large vessels are, however, costly additions to the dock works. The new lock at Avonmouth is to be 850 feet long, divided by intermediate gates into two chambers of 500 and 350 feet. Culverts are provided in the lock walls, large enough to fill and empty the lock at the rate of 2 feet per minute. The water lost by locking will be made good by powerful pumps.

Gates.

To close the entrance and retain the water either gates or caissons may be used. Gates are usually in two leaves, but in special cases they have been made in single leaves. They are most important features in the construction of a dock, and the most liable to damage and decay.

A dock gate has not only to support a head of water but it must bear the strain of constant opening and closing, the shock of waves, blows against the sill, straining caused by obstruction and possibly lifting bodily, all of which demand exceptional strength and excellence of workmanship. Surplus material must also be provided to ensure durability.

Whatever may be the form of design given to the gates, if facility of repairs is to be kept in view it is desirable that the meeting face of the gate and sill should be straight and not curved. The opening and closing machinery should be of the simplest character and hand gear should be provided in case of breakdown.

Gates are constructed of timber, iron or steel. Of the various timbers Greenheart offers perhaps the best resistance to the ravages of marine worms ; but, although not attacked in this country, it is by no means invulnerable in the tropics. In Algoa Bay (South Africa) Greenheart piles, fenders and walings, which had been in use only eight years, were found in several instances to have been attacked by the teredo. In the Bombay docks Greenheart gates were freely attacked by these animals, especially on the seaward side of the gates and on the underside of the ribs ; both teredo and pholas were found in the wood from the lowest rib up to a few inches above mean tide level ; for the first few years they appeared only in the corners of the large ribs where the less mature timber would be found, but ultimately they penetrated the heart-wood; the holes made by teredos were up to $\frac{1}{2}$ inch in diameter, and those made by the pholas were up to $\frac{3}{4}$ inch diameter by $1\frac{3}{4}$ inches deep. The teredo works in the direction of the grain and penetrates from end to end of the timber. The pholas works across the grain, but was not observed to penetrate more than about $1\frac{3}{4}$ inches deep.

Iron and steel have many advantages besides avoiding damage by marine animals, but on the other hand the question of corrosion of the metal must be taken into account.

Steel is well known to corrode and pit more rapidly than iron; consequently the outer skin plates in some gates have been made of iron, the interior framing being of steel. The interior of the gates should be of ample dimensions to allow space for thorough examination, cleaning and painting; otherwise rapid destruction may ensue.

German engineers have recently proposed that gates should be built of timber below low water level and of iron or steel above.

Where chains are used to open and close gates, a ram with multiplying sheaves seem to be more satisfactory than the rotary engine with either a barrel or a cup drum for hauling, because of the risk of damage to gearing and the cost of maintaining the rotary engine. For wide entrances the cup drum is more compact than the barrel, but it involves special links in that part of the chains which passes through the cup and the constant setting of the links to the proper size. With the ram and multiplying sheaves ordinary chain may be used, and no setting up of links is required when stretching begins.

Chains may be altogether avoided by the use of direct acting rams coupled to the gates. It is desirable to have the gate machines of moderate power so that an obstruction will bring them to rest. A search can then be made by a diver and the obstruction removed. An obstruction between the gate and the sill near the heel post is quite enough to burst the heel casting and force the gate off the pivot.

Caissons may be either floating, rolling or sliding. In still water, Caissons. or for dry docks opening out of wet docks, floating caissons are very convenient and are less trouble and occupy less room than sliding or rolling caissons.

They are sunk by admitting water to a tank below water line; the water is then pumped or lifted by an ejector to an upper tank above the water line and run out overboard when it is required to lift the caisson; or the water admitted for sinking may be retained in the lower tank and forced out overboard by compressed air at the moment of lifting.

At the outer or sea end of an entrance, caissons are sometimes difficult to get into place in a sea; and, until the tide has fallen sufficiently to give enough pressure to steady them, they knock badly in the groove and must be wedged. It must be borne in mind that floating caissons lift by flotation and they can only be lifted when the water is at a certain minimum level.

Booms.

To prevent damage to the gates and bridges by approaching vessels, floating booms or hanging chains across the entrance are useful as checks. The booms may be timber or iron, timber is preferable as it does not sink if damaged. Chain fenders may be either made fast at both ends, or one end may be attached to relieving gear which allows the chain to run out under the strain of a vessel against it, the resistance gradually increasing until it comes to rest.

Whether gates or caissons are used provision ought always to be made for temporary closing of the entrance during repairs. Sudden disasters such as the crashing of a steamer through the gates are fortunately of rare occurrence. But in building an important lock or dock entrance the possibility of serious accident, and the certainty of repairs being required sooner or later, ought to be borne in mind, and due provision made and maintained; and, should the time come for serious repairs at short notice, the value of making proper provision in the first instance will be fully appreciated.

Dock Walls.

The almost rectangular midship section of vessels has led to the face of dock walls being built nearly, if not quite, plumb instead of battering. The faces of the older dock walls were built with either a straight or curved batter, sometimes of considerable amount. The objection to a battering face is that the bilges of vessels lying alongside would rub against the wall and a vessel's stem may unexpectedly come in contact with it below water. This is illustrated in *Plate* III., *Fig.* 1, where a vessel approaching the wall at right angles could not touch below water, even if her stem were in contact with the coping; but, approaching at an acute angle, she might strike the wall below water, although some distance from it at coping level. The section of the walls is generally designed to withstand the pressure of the backing with no water in the dock; but this is not always possible and water may have to be admitted before the walls can be backed up. The walls may be built of rubble masonry, brickwork, or concrete; and faced with dressed stone, hard brick, or fine concrete. Timber fenders are added in some cases. It is convenient to provide a tunnel or culvert within the thickness of the upper part of the wall to contain pipes for hydraulic and sweet water and gas, and cables for telephones, power and light.

Some docks have sloping sides instead of walls. For general cargo, continuous wharves of timber are then constructed over the slopes or jetties are provided at intervals. Instead of timber, so-called ferro-concrete has been used in some cases for constructing wharves and jetties. Piles are made of this material by moulding concrete around a number of bars of iron or steel which are laced together by thin bent iron rods. The piles are driven in the ordinary way except that a cushion is interposed between the top of the pile and the ram. The superstructure is of similar construction moulded in place. It is claimed that this system possesses strength and freedom from decay and from attacks by sea worms.

Wharves and Sheds.

On the wharves, and in the arrangements for handling and delivering cargo and working traffic to and from the ship's side, the development of shipping has brought with it an expansion to meet the requirements of despatch even more remarkable than the changes in the internal dimensions and form of docks and locks.

The loading and discharging of a cargo may proceed at the rate of 120 to 130 tons per hour day and night. For shorter spells each crane may be lifting cargo into or out of the hold at the rate of 70 or 80 tons per hour, and coal is loaded at the rate of 400 to 500 tons per hour. Such quick despatch cannot be provided for without very large quay and shed accommodation and ample and easily worked railway sidings. In the new docks at Avonmouth the land area is about six times the water area. The coal sidings at Barry average three miles in length to each coal tip. In the present Avonmouth dock there are upwards of ten miles of sidings and the new dock will have a still larger proportion; the new sheds are to provide 175,000 square feet area for each berth. No rule can be laid down for the arrangement of wharves and sheds. The practice varies in different ports, and in the same port, with regard to the distance sheds should be from the coping. In some cases the sheds are only a few feet off which is advantageous for certain classes of cargo. In other cases there may be a space of 40 to 50 feet between the coping and the shed, sometimes open and sometimes covered over. With such large quantities of cargo to be handled rapidly, it is important to lay out the wharf arrangements in such a way that the import cargo can be quickly removed from the ship's side, sorted, and delivered to the consignee or removed to warehouse; and that export cargo can be brought alongside ready for shipment as soon as the holds are clear and ready to receive it. In ports where the trade is import or export only the conditions are somewhat simplified; but, perhaps for the very reason that vessels must then go to two ports, the despatch at each is required to be quicker.

When there is sufficient room, the most convenient arrangement of sheds consists of large single-floor buildings, with either revolving shutters or "hit-and-miss" doors along the entire front; but, as this takes up so much ground, double and treble storey sheds are built. A single and a double storey shed are shown in *Plate* XX. In upper storey sheds it is found convenient to space the columns as far apart as can be arranged consistently with economy and strength. For receiving cargoes on the upper floors, outside galleries or terraces forming upper wharves are provided, or hinged flaps capable of being raised out of the way are fixed to the front of the sheds.

The sheds for ordinary cargo in transit must be not only well lighted and roomy but modern requirements are demanding a further provision. Modern rapid transit has introduced the method of cold stowage on board ship of perishable articles of food which could not be transported over sea except in cool chambers in quick ships. Such articles are warehoused till required for consumption either in cold stores to keep them or, in case of fruit, in warm stores to mature them. Arrangements may therefore be required on wharves to prevent these articles being spoilt or damaged by exposure between the ship and the warehouse.

Sidings.

With regard to railway access to wharves, especially if the dock walls are in long unbroken lines, care must be taken that traffic can be worked in and out easily without blocking the running lines or interfering with wagons on the loading lines; and that full and empty wagons can be readily brought up and removed without interfering with the work of loading or discharging. Standage sidings, easily reached without back shunts, are necessary to effect this; and the extent required for a large dock may be estimated from what has been said as to the size of modern cargoes and the rapidity with which they have to be handled.

Elevators and Transporters.

For lifting ordinary cargo into or out of a ship either the ship's gear or cranes on shore are used, driven by steam hydraulic pressure or electricity. For heavy machinery floating cranes are sometimes used which can be brought alongside and thus avoid shifting the ship to a fixed crane.

The lifting chain or rope in hydraulic cranes is usually worked by rams with multiplying sheaves. In electric cranes the lifting rope is on a drum driven by a motor through a clutch, and lowering is done by a brake.

The cranes are placed either on the wharf or on an upper gallery or on the roof of the shed, or they may be carried partly on the wharf and partly on the shed according to the space available for them.

Grain in bulk is lifted out of vessels by elevators either of the continuous bucket type or of the pneumatic type. The continuous bucket elevator is similar in action to ladder and bucket dredging machines, while the pneumatic elevator sucks the grain up through pipes from which the air is exhausted by powerful air pumps. Both kinds of elevators are sometimes erected on shore, and sometimes afloat on barges or pontoons in order that they may be moved from one vessel to another. From the ship's side grain is conveyed to the granary or warehouse on endless bands made of canvas and rubber and driven by electricity or hydraulic power. At the Millwall docks timber is conveyed on revolving rollers erected on trestles from the docks to the stacking ground situated a considerable distance away.

Dry Docks.

One of the most essential features in the equipment of a harbour is the provision of some means by which the water may be removed from the ship or the ship from the water. This is necessary, not only for repairing damage below water line, but for cleaning and painting the hulls of vessels which must be frequently scraped clean from weed and shells which retard their progress through the water and also be kept well protected by paint from corrosion. It is also necessary to inspect or "sight" the bottom of vessels in case of suspected damage and for the periodical examinations for survey and insurance purposes.

Graving Docks.

To remove the water from the ship she is either placed in a graving dock or on a gridiron. A graving dock (as defined in the Admiralty dock book) is usually an excavated dock faced with solid masonry, into which the water may be admitted and either pumped out or let out so as to leave a vessel resting on blocks and supported by shores.

Graving docks, as defined in the Admiralty dock book, are the usual means employed for dry docking vessels. For naval purposes they are designed so that support can be given to the armoured portions of a vessel and under the heavily loaded parts occupied by engines and guns. You are no doubt familiar with the example of a modern naval dry dock in course of construction in this dockyard. For commercial purposes the section is rather different; an example is shown in *Plate* III., *Fig.* 3. The altars are only provided where side shores are required. Special provision for bilge shores and props is not necessary. When they are required, as in the case of a vessel docking with cargo on board, the ordinary floor is sufficient to carry the weight. The water is removed generally by pumping, as running off by gravitation (even when the fall of tide is sufficient to allow this to be done) is too slow for a large dock. In modern dry docking operations despatch is as essential as in wet docks. The largest vessels are scraped and painted in 24 hours; such rapid work being necessary, not only to avoid delay to the vessel, but to prevent interference with the refrigerating appliances on board.

The pumps must therefore be large enough to remove the water very rapidly until the vessel takes the blocks; and to complete the emptying as soon as the scraping of the vessel's sides is finished, this operation being carried on from floating stages as the water is gradually lowered.

The entrance to a graving dock is closed by gates or a caisson and the culverts and sluices for filling and emptying are similar to those in connection with a lock.

Gridirons.

A gridiron usually consists of balks of timber placed parallel to one another on the fore shore below high-water mark and in such a position that a vessel may be moved over the gridiron at high water and left dry resting on it at low water.

The usefulness of gridirons is restricted by the range of tide and by the fact that they only permit of work being done on them which can be executed between tides.

Floating Docks.

For removing a ship from the water floating docks, lift docks and patent slips are used.

Floating docks are watertight structures capable of being submerged by the admission of water and raised again by pumping out the water. They are fitted with blocks similar to those in a graving dock for vessels to rest upon.

The dock is sunk low enough for a vessel to float over the blocks, the water is then pumped out and, as the dock rises, it lifts the vessel out of the water.

Sometimes floating docks are made in sections so that one or more ections can be used separately for vessels of moderate size and thers added, as necessary, for large vessels.

Depositing floating docks are so constructed that, after a vessel ias been lifted, the dock can be moved alongside a fixed staging, the ›ontoons passing between the piers and the staging. The dock is hen lowered, leaving the vessel resting on the staging; and it is hen free to lift another vessel.

A balance dock is a form of floating dock, the bottom of which is ›f a somewhat circular form in section, and permits of the dock ›eing heeled over in order to clean the bottom. The Bermuda dock, ›uilt in 1866, was of this form. In the more modern docks the ›ontoons forming the bottom can be taken out in rotation and ifted out of the water on the dock.

The usefulness of a floating dock is limited to vessels which are ›f somewhat less dead weight than the lifting capacity of the dock ind to the lifting capacity of the sections over which the heavy part ›f a vessel may be placed; and care must be taken to avoid overstrain, which may cause serious buckling. They are, however, now ›eing built capable of lifting vessels of 17,000 tons weight. Their great advantage is that they require no foundations except the water hey float in, they can be built at home and towed to any part of the vorld, and they can be employed in positions where for other easons than the absence of good foundations a graving dock would ›e impossible.

In lift docks the vessel is floated over a pontoon placed over **Lift Docks.** girders, the ends of which are suspended by links between two rows ›f hydraulic lifting cylinders. The vessel is raised by hydraulic pressure on rams in the cylinders. Hydraulic lift docks have not come into general use.

A patent slip consists of a cradle supported on carriages and run- **Slips.** ning on rails laid on an incline into the water. The cradle is run out to receive the vessel, and is then hauled up by hydraulic power or steam until the vessel is clear of the water. It may be noted that patent slips are not used for the largest class of vessels.

Dock Construction.

In dock construction the site has usually to be dug out to the **Excavation.** required depth over the whole area. *Plate* III., *Fig.* 3, shows sequence of operations. The top (1) may be excavated to a convenient depth and then trenches (2) sunk for the walls; the dumpling or enciente

(3) being removed after the walls are built up to the top of the trenches.

The whole of the excavation may be done in the dry by hand, or machinery may be employed, or the dumpling may be removed by dredging after the walls are built. For excavating by machinery steam navvies of various types are used; one of Ruston & Proctor's machines being equal to about 60 navvies. Another kind of machine, known as a "Lubecker," is really a land dredger. In the trenches the excavation is all hand work. After excavation the spoil has to be removed to the depositing ground either by tip wagons hauled by locomotives, or by some other means. Under certain circumstances it may be better to dredge the dumpling, and then the excavated material is either taken to sea in hopper barges and thrown away or it is deposited on land for filling. For depositing dredged material on land, it may be filled into skips carried on barges which are lifted ashore and emptied by a crane; or it may be discharged direct through long shoots and assisted to flow by water; or it may be filled into barges and then, after mixing with a plentiful supply of water, be pumped ashore and conveyed through long pipes to the depositing ground. Rock is removed by blasting; or heavy iron rock breakers, on the system invented by Messrs. Lobintz, may be used when blasting is inadmissible.

The sides of the trenches for the walls are supported by sheet piles, runners or polling boards, walings and struts.

Instead of trenching and building up from the bottom if the ground is very soft, hollow columns of cylindrical, rectangular or other section are sunk from the surface. A short length is first built up on a shoe or curb, of wood or iron, and the earth inside is excavated; the weight of the column or monolith, with perhaps some kentlidge added, causes it to sink. Further lengths are added till the required depth is reached. The hollow interior is then filled in; and the intervening spaces, after being closed at the ends by sheet piling, are excavated and filled in. When these methods are inapplicable it may be necessary to use caissons from which the water is excluded by compressed air. Piled foundations are also used when the circumstances indicate that they are necessary.

Walls.

The choice of materials for building the walls depends to some extent on local circumstances of price and available supply of stone, concrete materials and bricks. Excellent work is done with rubble stone masonry faced with medium-dressed blocks well bonded into the backing. Concrete may be faced with stone or brick or with a finer description of concrete, the object being to make the face as impervious as possible. The coping should be heavy ashlar of hard stone not dressed too smooth. The necessity for providing weeping holes or vents for water behind the walls, and dry rubble drains to lead to them, must not be overlooked. Other details require attention, but I should exhaust your patience if I were to proceed further on a subject which is practically inexhaustible.

CONCLUSION.

Though this lecture has been mainly on harbours and docks intended for commercial purposes, I hope it has not been without interest to you. The arrangements for quick despatch of merchant vessels are of value in the despatch of military expeditions in which you may all be called upon to take part; and, if you should be associated with harbours and docks as executive or administrative officers in India or elsewhere, you will probably find no work more full of variety or more worthy of your attention.

PAPER VIII.

THE SURVEY OF INDIA.

(*Lecture Delivered at the School of Military Engineering on 27th November*, 1902, *by* LIEUT.-GENERAL C. STRAHAN, R.E.).

I PROPOSE to give a short sketch of the history of the Survey of India, and a brief outline of the work now carried on by that Department. For all the early historical information I am indebted to the two memoirs on the Indian Surveys by Clements Markham and by Charles Black.

Up to the year 1800 scarcely any attempt was made to survey the country accurately; part of Bengal as far north as Agra had been roughly mapped, and surveyors had been attached to the armies that had taken the field in different parts, and they had brought back route maps and reconnaissances, by which means a considerable amount of information had been accumulated, but nothing had been published.

It was not until later that a scientific survey was commenced. This was suggested by an officer of the 33rd Regiment, William Lambton by name, who had served under Lord Wellesley during the Siege of Seringapatam. After the fall of Tippoo, Major Lambton submitted a project for the measurement of an arc of the meridian and for a trigonometrical survey across the peninsula. This project was approved of, but the necessary instruments could not be procured till 1802.

From this time the operations may be divided into three more or less distinct branches, the trigonometrical and scientific, the topographical, and the revenue. I will first deal with the trigonometrical and scientific branch.

Trigonometrical Survey (*Map* I.).

The instruments made use of by Lambton were a 36-inch and an 18-inch theodolite, a zenith sector of 5 feet radius, and two steel chains, one of which was kept as a standard, by which the chain in actual use was constantly checked. The point of origin of the survey was the Madras Observatory; it became therefore of the greatest importance to fix the position of this with the utmost accuracy, as on it depended the position of India as a whole; it was comparatively easy to determine the latitude with considerable accuracy, but it was not nearly so easy to ascertain the true longitude; it was measured, as well as it could be in those days, by observations of eclipses of Jupiter's satellites and by lunar distances; the results were by no means concordant, but Lambton eventually adopted 80° 17′ 21″ E. longitude for the survey.

Actual work was commenced in 1802, by the measurement of a base line 7½ miles long in the neighbourhood of Madras; the steel chain was fitted into five coffers of wood, each 20 feet long, which were supported on tripods with elevating screws. From this base line a chain of triangles was carried up to the plateau of Mysore, where a base line of verification was measured, and from this the triangulation was extended to the Malabar coast. In measuring the horizontal angles Lambton took them three or four times; and each time the object was intersected the microscopes were read three times, but no change of zero was made.

The distance across the peninsula thus obtained was found to be 40 miles less than that shown on maps of the day, thus proving the absolute necessity of a trigonometrical survey. Major Lambton then turned his attention to the measurement of an arc of the meridian, and the chain of triangles that was observed for that purpose is known as the Great Arc Series. By 1811 Major Lambton and his assistants had completed this series from Cape Comorin to Bangalore, besides covering nearly the whole of the southern part of the peninsula with a network of triangles. On one occasion, when hoisting the great theodolite to the summit of the Tanjore Pagoda, one of the guys gave way, and the instrument was dashed against the wall with great violence, distorting the limb. Such a catastrophe might well have discouraged any man, but Lambton never lost heart; he hurried back to Bangalore, where he shut himself up in his tent with a few Ordnance artificers, and in six weeks he had with patience and skill brought it back to nearly its original form; the instrument remained in use for upwards of 20 years after this. The actual amount of damage done to the graduation was never known, but this accident eventually led to taking the horizontal angles on different parts of the limb, so as to eliminate as far as possible any inaccuracies in the graduation. This system has been in use ever since, and all angles of the principal triangles are repeated not only on two faces, but on several parts of the limb.

Difficulties in the field were not the only ones; Lambton had many others to contend with. The utility of his work was called in question, and his resources were crippled by the Finance Committee at Madras. Even the scientific societies in Europe gave him no encouragement, and for years he never received any sympathy or advice from Government or from the Royal Society; eventually however, in 1817, he was made corresponding member of the French Institute, and in 1818 he was elected a Fellow of the Royal Society. In January of that same year the Governor-General at last recognized the importance of his survey and transferred it to his immediate control, ordering it to be called the Great Trigonometrical Survey of India, a title which it has held ever since.

Capt. G. Everest, R.E., had been appointed Lambton's chief assistant in 1818. At that time Central India was in a most unsettled state, and instead of attempting to push on the Great Arc, Lambton employed his parties in triangulating the country between the Kistna and Godavery Rivers. Everest was despatched on this duty, and overcame the difficulties arising from the disturbed state of the country; but he was prostrated by jungle fever, which forced him to take leave to the Cape of Good Hope to recruit. In the meantime Lambton, who was now aged and much broken, again proceeded with the Great Arc; but it was a last effort, and on the 20th of January, 1823, he died on the road to Hinganghat, at the age of 70. His work comprised the measurement of the Great Arc from Cape Comorin to Berar, and upwards of 165,000 square miles of triangulation in Southern India. He was succeeded by his assistant, Capt. Everest.

In December, 1823, Everest attempted to prolong the Great Arc, but he had to face many difficulties arising from the death of his colleague, Dr. Voysey, the retirement of his chief assistant (a half-caste from Madras who did not relish the exposure and hard work), and the unhealthiness of the country, which at last brought on a severe attack of jungle fever, causing partial paralysis; still he persevered, but he had to be lowered into and hoisted out of his observing seat. In spite of all this he succeeded in carrying the series over the Satpura range on to the Sironj plateau, where a base line was measured with the old chain. Early in the year 1825, however, he completely broke down, and was obliged to go to England, where he remained for five years, employing his time in studying the latest improvements and in superintending the construction of new instruments on the most approved principles. He took back with him a 36-inch theodolite and two double vertical circles, 36 inches in diameter; also a complete set of compensation bars, to take the place of the old steel chains.

About this time a most important change in the procedure of the field parties was made. Up till now the surveyors had been kept in the field all the year round; opaque signals only had been used; it was therefore necessary to observe during that portion of the year when the atmosphere was clearest, that is, in the rainy season. On the high plateau of Mysore this was not of so much consequence, but on proceeding northwards Everest found the climate so deadly that a change had to be made, and the out-of-door work was thereafter done during the cold dry season, the surveyors retiring into recess quarters for the hot weather and rains. This necessitated the use of luminous signals, the atmosphere being as a rule too thick to allow of flags and poles being seen; Everest then introduced heliotropes to flash the sun by day and powerful Argand lamps for use by night.

On Everest's return in 1830 he found that the longitudinal series from the Great Arc to Calcutta was nearly finished, and he decided on measuring a base line of verification with the new bar apparatus; the site he selected was along the road from Calcutta to Barrackpore, along which it extends for $6\frac{1}{2}$ miles. He then resumed the work connected with the Great Arc, but he had first to overcome many difficulties, which could have only been surmounted by a combination of qualities rarely met with in one man. He had to train his staff, and in addition to his incessant labours in the field, he had to transact all the business connected with his office as Surveyor-General, for in him had been combined the two appointments of Surveyor-General and Superintendent of the Great Trigonometrical Survey. Moreover, the series, which had hitherto had the advantage of hills on which to erect the stations, had now reached a flat country thickly covered with villages and groves of trees, which completely obscured all distant views ; to obviate this, solidly built towers were erected, high enough to see over the bulk of the trees and other obstacles (*Figs.* 1 to 7, *Plate* I.).* At first the selection of the sites for these stations was made with the assistance of a mast 30 feet high, surmounted by a circular table, on which was placed a 12-inch theodolite ; round this was built a square bamboo platform for the observer ; thirteen other masts, 70 feet in height, carried signals. But this was found to be a cumbersome method, and he then introduced the system of ray tracing, as it was called ; this consists of a traverse run between the two mutually invisible points, from which their relative direction can be calculated, so as to admit of a line being carried between them ; along this all obstacles can then be cleared, or, failing that, one or both of the points must be shifted.

Day and night at all hours Everest was at work, but it was not till May, 1834, that all the stations between the Chambal River in Central India and the foot of the Himalayas had been selected. In the end of that year the most northern base line of the Great Arc was measured in Dehra Dun, twice in opposite directions ; the difference between the two determinations was only 2·4 inches. The Sironj base was re-measured with the same instruments, and was found to be 2·8 feet too short. In the years 1834–35 all the angles of the triangles across the plain were observed, and the series was connected with the Dehra base. Thus was completed the Great Arc, which extends throughout the entire length of India, from north to south. In addition to this great work, the Bombay longitudinal series was executed by Everest. He also designed and partly carried out a scheme for covering Bengal and Behar, in the southern part of the peninsula, with a gridiron of chains of triangles instead of Lambton's network. The gridiron system may be described as one of meridional series of triangles, tied together at their extremities by longitudinal series, thus forming a figure resembling a gridiron. These series have generally been made to follow closely meridional or longitudinal lines ; thus the Great Arc follows the 78th meridian, and the longitudinal series from Calcutta to Karachi keeps as nearly as possible to the parallel of latitude of 24 degrees.

Colonel Everest finally quitted the scene of his labours and triumphs in 1843. He had completed one of the greatest works in

* *Figs.* 8 *and* 9, *Plate I., show the towers employed since* 1852.

the whole history of science; no scientific man ever had a greater monument to his memory than the Great Arc of India. His was a creative genius; the whole conception of the trigonometrical survey as it now exists was the creation of his brain. He substituted the gridiron system for that of the continuous network; he introduced the compensation bars; he improved the system of observing by the change of zero; he invented the plan of observing to heliotropes; and he designed the towers. There have been modifications and improvements since; but nearly everything of importance connected with triangulation was originated by this great geodosist. He was made a C.B. and knighted in 1861. He was succeeded by one of his assistants, Capt. A. Waugh, R.E., of whom he said that "he had attained a decree of accuracy and perfection of skill which it would be impossible to surpass."

Waugh took charge in 1843, and, like his predecessor, received the double appointment of Surveyor-General and Superintendent of the Great Trigonometrical Survey. His first work was to complete the project for the triangulation between the Great Arc and Calcutta, which I have already mentioned. Regarding the several series which cross this area, I should like to allude especially to the difficulties and dangers incurred by the officers who had to carry on that which connected the northern ends of the different meridional series. It was commenced in 1845 and completed in 1850, and is the longest series between measured bases in the world, extending for no less than 1,690 miles from Dehra Dun to Sonakhuda, in Purneah. In consequence of the refusal of the Nepalese Government to allow it to be carried through their country, the stations had to be located in the deadly tracts of marsh and jungle which lie along the foot of the Himalayas. In 1847 no less than 40 natives died of jungle fever, and Mr. Logan, the observer, was himself prostrated, and the whole party was conveyed in a helpless condition to Gorakpur. Lieut. Reginald Walker then took charge, but he was also attacked, and was found dead in his dooly when hurrying up to Darjeeling. The completion of the worst part of this series is due to the courage and perseverance of Mr. Logan, who died three years later from the effects of disease contracted at this time. Of the five officers who held charge of it at different times, Colonel Waugh himself being one, two retired and two fell victims to the climate. From the stations of this series were fixed the mightiest peaks of the Himalayas; the rays to these were in many cases of great length, the longest being upwards of 200 miles. The loftiest peak was well named by Waugh after his old chief, Mount Everest; it is the highest known in the world, and is 29,000 feet in height.

Waugh extended the gridiron system to other parts of India, but time will not allow of my entering into details of how the various difficulties met with by the observers were overcome; at one time having to work their way through deadly jungles, at another having to carry their work through a waterless desert, where special arrangements for the supply of both food and water had to be made, not only for the observer's own camp, but also for the outlying camps of the signallers; in Kashmir, where they had to observe at stations far beyond the limits of perpetual snow, even up to 18,000 feet, whilst the signallers showed their heliotropes from peaks up to 20,000; building materials for the stations had to be dug out of the snow, and on one occasion the surveyors were detained for 33 days owing to the storms of snow and the foggy weather.

A series of levelling operations to determine the heights of base lines in the interior was instituted by Waugh. Reciprocal vertical observations had already been taken at all the trigonometrical stations; but, owing to the very uncertain effects of refraction, the results were not always reliable; taking into consideration this and the great lengths of the series, it was thought desirable to check the heights thus obtained by lines of levels. In 1858 these levels were commenced by Major James T. Walker, R.E., and he connected the Karachi, Chuch, Dehra, and Sironj bases with the sea. The errors thus discovered varied from 1 foot 8 inches to 5 feet 1 inch.

Waugh became a major-general and was knighted in 1861; he retired in March of the same year, having been Surveyor-General for 17 years. His labours were recognized by the Royal Geographical Society, and in 1856 he was awarded its Gold Medal.

On the retirement of Sir Andrew Waugh, the two offices of Surveyor-General and Superintendent of the Great Trigonometrical Survey were once more separated, after having been united for 31 years. Colonel H. L. Thuillier became Surveyor-General and Major J. T. Walker Superintendent of the Great Trigonometrical Survey.

The gridiron system and the measurement of base lines were vigorously carried on under Walker. The base at Vizagapatam was first taken in hand, and was completed in two months, in the autumn of 1863, by Walker himself, assisted by three other Engineer officers. The difference between its measured length and that computed from the triangulation starting from Calcutta, 480 miles distant, was only half an inch. This base line was then connected with the Madras Observatory, Lambton's starting point 60 years before. A few years later it was decided to re-measure the base lines at Bangalore and Cape Comorin, and to revise the intervening triangles with the more modern instruments. Owing to the changes in the surface of the country, it was found necessary to select new sites for the base lines. The Comorin base was the last required for the verification of the triangulation of India proper, and the tenth that had been measured with the bars taken out by Everest in 1830. Under the superintendence of Walker the triangulation of India proper was thus completed.

Levelling Operations.

The spirit levelling operations, which Walker himself had commenced under Waugh, were continued by him, and a line of levels connecting Karachi with Calcutta was finished, being the longest and probably the best line of its kind that has ever been run; it is 2,200 miles in length. Branches from this main line join it on to the railways of Delhi, Lahore, Mooltan, and other places.

Observations for Longitude.

For topographical purposes the values deduced from the triangles are all that are necessary, but for accurate geodetic purposes astronomical determinations of the stations, or at all events a certain number of them, are also required. In 1863 two parties were organized to take observations for latitude and azimuth; one party was to begin at Calcutta, and take observations along the Calcutta Longitudinal Series at the stations whence the Meridional Series emanated, whilst the other was to work on the Great Arc, selecting stations at about 1° apart. In 1876 the determination of differences of longitude by the electric telegraph was commenced, the latitude observations being held in abeyance meanwhile. In the first year arcs between Bombay, Haiderabad, Bellary, Madras, and Bangalore were measured; in the next year three other arcs in India were added, and then the two officers (Capts. W. M. Campbell, R.E., and W. J. Heaviside, R.E.) proceeded to find the differences between Bombay, Aden, and Suez, in order to complete the connection between England and India, of which the section from Greenwich to Suez had already been determined on the occasion of the transit of Venus in 1874, under instructions from Sir George Airy, the Astronomer Royal. The result of these measurements was to reduce the longitude of the Madras Observatory by 2′ 31″ of arc. In

1895–96 a second determination was made *viâ* Karachi, through Persia to Potsdam and Greenwich, which still further reduced it to 80° 14′ 46″·7; this may be looked upon as final; any future alteration that may be made will be of so small an amount as only to affect the most rigorous calculations of the figure of the earth.

A result of these longitude observations was to show a difference of nearly 14″ of arc between the longitude of Madras and Mangalore (on the east and west coast respectively), as determined by triangulation and by the telegraph, the former being the greater. This is consistent with the result of pendulum observations, which show that the density of the earth's crust is greater under the depressed beds of oceans than under the elevated portions of land. In consequence of this the plumb line at Madras is probably deflected to the east, whilst at Mangalore it is deflected to the west, thus making the astronomically determined difference of longitude less than it actually is.

These pendulum observations had been commenced by Capt. J. P. Basevi, R.E., in 1865, under the instructions of Colonel Walker. In the course of the next five years he swung the pendulums at nineteen stations on the Great Arc, at two stations on the east, at two stations on the west coast, and in Minikoi (one of the Laccadive Islands). He then started for the lofty plateaus of Thibet; he there swung the pendulums at a station on the More Plain at a height of 15,500 feet above the sea; thence he made his way back to the Upper Indus, and, although suffering from a severe cold, he set up his instruments on a mountain in Ladak, 17,000 feet in height. There, protected only by a tent, in a climate where the thermometer rose to 70 or 80 degrees in the afternoon, and fell below zero at night, his illness increased; one morning, when gallantly striving to rise from his bed to commence work, he died. The operations were subsequently carried on by Capt. Heaviside, who swung the pendulums at some stations in India, and then proceeded to England, swinging them *en route* at Bombay, Aden, and Ismailia, in Egypt. I have already alluded to one interesting fact that was deduced from these observations; another was that the density of the earth's crust is less under and near the Himalayas than under the plains to the south.

Tidal Survey.

Yet another important set of operations was set on foot by Walker, viz.:—Observations to record the height of the tides, in order to ascertain the changes in the relative height of land and sea which were believed to be occurring, more particularly on the coast of Kattiawar, and also to determine the mean sea level at various points on the Indian coasts. Some observations had been taken in a desultory way in the Hooghly, at Madras, Bombay, Karachi, and a few other places. Mr. Parkes had also taken tidal observations at Karachi and Bombay, and had computed very accurate tables for those two ports. But more than this was now required, and in 1868 Walker was requested to take steps to obtain the necessary self-registering tide gauges, and to connect the selected tidal stations by accurate lines of levels. But the proposed operations were postponed for four years; and it was not till 1872 that Lieut. A. Baird, R.E., was deputed to study the practical details of the method of tidal registration and the harmonic analysis of the observations, as practised by the British Association. Six new gauges with chronometric escapements were made, and with each gauge self-registering aneroids and anemometers were supplied. Baird selected three stations at the head of, at the entrance to, and about half-way up the Gulf of Kutch. The preliminary result of a year's observations at these stations was to show that the mean sea level at the head of the gulf is 7 inches higher than at the mouth. Subsequently Baird arranged for tidal stations at Bombay, Karachi, Aden, Madras, and other places along the coast; at each a man was placed in charge of the instruments, and taught to manipulate them; the correct time, which is a most important factor in the operations, was obtained from the telegraph office, one of which was to be found at nearly all the places selected. At those which were out of reach of telegraph offices chronometers were supplied, or, if they were not available, a sun dial, devised by Colonel George Strahan, R.E., was given, by which, when the sun is near the meridian, the time can be estimated within 10 seconds or even less. In 1880–81 the stations at Bombay and Madras were connected by a line of levels carried across the peninsula; the line was 730 miles in length, and for the most part ran near the railway. The result was that the mean sea level of Madras was made out to be about 3 feet higher than that at Bombay. It is supposed that the discrepancy may be due to local attraction of the hills and table lands over which the levels were carried, or else to an accumulation of small errors. The total number of places at which tidal observations have been or are being taken is 41, extending from Suez to Port Blair, in the Andaman Islands. Seven of these have been made permanent observatories, whilst at the others observations were taken usually for five years.

The tide gauges have on more than one occasion furnished some interesting results regarding earthquakes. In December, 1881, there was an earthquake in the Bay of Bengal, which was very violent in the Andamans and Nicobar Islands, and was felt all along the east coast of India, and slightly on the west coast. The earth waves appear to have lasted for a few seconds only, but the ocean was greatly disturbed. Major M. W. Rogers, R.E., was at this time triangulating on an island near Tenasserim, and was at the very moment observing to one of his stations some 15 miles off; he actually saw the earthquake before he felt it, for he saw the signal rise and fall in the field of his telescope; then, on looking at his instrument, he saw the levels were violently agitated. Again, the gauges recorded the effects of the great eruption of Krakatoa, in Java, on the 27th and 28th of August, 1883; the primary effect was a marked fall in the sea level, which was succeeded by a great positive wave; great waves, ranging in height from 22 inches at Negapatam to 9 inches at Aden, 4,000 miles distant, were registered at all places which were so situated as to receive the full force of the disturbance.

Exploration in Thibet.

About 1860, whilst Capt. T. G. Montgomerie, R.E., was engaged on the survey of Kashmir, it occurred to him that it would be feasible to employ trained natives to explore portions of Central Asia which it would be impossible for Europeans to enter; he accordingly selected some men and proceeded to train them to run route surveys with a compass, pacing the distances, and to take meridional altitudes with a sextant. After much trouble and many disappointments, one man was found suitable, and sent to Yarkand, the position of which he fixed; another died on his way home under very suspicious circumstances; whilst a third was sent towards Chitral, but he had a blood feud in his family, and the avenger followed and murdered him. After this the scheme met with better success. In 1865 Pundit Nain Singh, a Bhutiya, after two unsuccessful attempts to pass the Chinese outposts on the boundary of Thibet, succeeded in getting to the Sanpu, as the portion of the Brahmaputra north of the Himalayas is called, and there he joined a caravan sent by the Rajah of Kashmir to the Government of Lhasa. Travelling with this caravan he reached that place, where he stayed for some time, and made a sketch map of the town. On another occasion he and another man, after a most trying journey, during which they crossed a pass 18,760 feet above the sea, reached the gold mines of Thok-jalung. On retirement this Pundit not only received his well-earned pension, but the Government gave him a village in addition, and he was awarded the Gold Medal of the Royal Geographical Society. The most remarkable journeys of any native explorer were made in 1878–82 by Kishen Singh, a first cousin of Nain Singh, by whom he was trained; one much vexed question he set at rest, and that was whether the Sanpu formed the upper part of the Brahmaputra or the Irrawaddy. From the northern side of the Sanpu he made his way east and south until he arrived close to the boundary of Assam without crossing that river, thus showing that it could not flow into the Irrawaddy. Although so close to home, he was unable to pass through the last few miles, owing to the hostility of the inhabitants; and he was forced to make an enormous detour in order to once more reach India. Kishen Singh was rewarded by a free grant of land and the title of Rai Bahadur, a sum of money from the Royal Geographical Society, a Gold Medal from the Paris Geographical Society, and another from the Venice Geographical Congress. The adventures experienced and the hardships undergone by these native explorers are full of interest, and I should like to dwell more upon them, but I must pass on to other subjects.

Re-Organization of Department.

In 1878, when Walker became Surveyor-General, Government called upon him to re-organize the department, and to amalgamate the three branches which had up to this been virtually separate departments, each with its own cadre of officers and establishments. As time went on the special scientific duties of the Trigonometrical Branch gradually approached completion, and many of its officers were employed on topographical work; and, similarly, the work of some of the revenue parties was more of a topographical than of a revenue nature. The duties of the three branches had thus become much intermixed, whilst it was found impracticable to be constantly transferring officers from one branch to another, according to the work they were employed on. The amalgamation was carried out, but not without difficulty, and in some cases not without damage to individual prospects, more especially as at the same time extensive reductions were ordered. The united department was then styled the Survey of India, and was administered by a Surveyor-General, who was also Superintendent of the Great Trigonometrical and of the Topographical Surveys, whilst a Deputy Surveyor-General superintended the Revenue Branch. On General Walker's retirement this was again altered, and a Superintendent of the Trigonometrical Branch was added, the Surveyor-General retaining the supervision of the Topographical Branch.

Computing Office.

Hitherto I have alluded to only the field parties of the trigonometrical surveys. Preliminary values had been computed of sufficient accuracy to afford a basis for the mapping; but the final determinations, in which all the different circuits forming the gridirons should be consistent not only each in itself, but with all the others, had yet to be made; this was beyond the powers of the field parties, who had hitherto carried on the preliminary calculations during their recess seasons; so a computing office was organized at Dehra Dun; and the results, as they were completed, were published in the volumes of the *Account of the Operations of the Great Trigonometrical Survey of India.* Of these, nine were published under Walker; Vol. No. I. treats of the Base Lines; Nos. V. and IX., of the Pendulum and Longitude Operations respectively; and the remainder of the Triangulation. It will thus be seen that during Walker's time, not only was great progress made in the operations which had already been started, but that several other most important ones were initiated. He was indefatigable in work, never sparing himself, as is evidenced by the fact that he found time to issue nine of the great volumes in addition to his onerous duties as Surveyor-General and Superintendent of the Trigonometrical and Topographical Surveys. Of his abilities, these volumes alone afford ample evidence. For his military services on the Trans-Indus Frontier and in the Mutiny he was made a C.B., and he was also a Fellow of the Royal Society. He left India in 1883, and died a few years after.

Colonel C. T. Haig, R.E., succeeded him as Superintendent of the Great Trigonometrical Survey, and Colonel G. C. Depree, Indian Staff Corps, as Surveyor-General and Deputy Surveyor-General of Topographical Surveys.

The principal triangulation in India proper having been completed, attention was directed to its extension into the countries on either side of it. In Burmah a more accurate basis for the topographical surveys was required, so in 1889 a series, emanating from that which had been carried along the west coast, was commenced; it was to run northwards through Mandalay up to the latitude of 25°, whence it was connected to the west by a series through Manipur. Great difficulty was experienced in observing across the Chindwin valley on account of the want of elevated positions from which to see over the huge jungles, and also on account of the haziness of the atmosphere. The difficulty was finally overcome by using special acetylene lamps with powerful parabolic reflectors, devised by Capt. H. A. D. Fraser, R.E., which could be seen across the whole valley.

In Baluchistan, on the extreme west also, accurately fixed stations were necessary to strengthen the mass of secondary triangulation which had gradually accumulated there; a principal longitudinal series was therefore started in 1894 from the Great Indus Series, to run through Mekran. This unfortunately came to an abrupt and a most unpleasant end; for in the third year the party was attacked at night, and the headquarters camp was completely looted, the theodolite hopelessly damaged, and 13 natives were killed. Capt. J. M. Burn, R.E., the officer in charge, was luckily sleeping on a small hill at a short distance from the main camp, and he and the men with him escaped, but with great difficulty and no little hardship, as they had to make their way as best they could for 130 miles to the nearest European station. It has not been considered desirable even yet to continue this series, which will in all probability form a connecting link between the Indian and European surveys.

Meanwhile tidal observations and the accompanying levelling operations were carried on without a break. The electro-telegraphic determinations of differences of longitude, which had been unavoidably stopped, were re-commenced as soon as two suitable officers could be spared, and after the instruments had been thoroughly overhauled and strengthened; in the intervals the latitude and azimuth observations were resumed.

Colonel Haig retired in 1888 and was succeeded by my brother, Colonel George Strahan, R.E., who in his turn was succeeded in 1894 by Colonel St. George Gore, R.E., the present Surveyor-General. The present Superintendent of the Great Trigonometrical Survey is Lieut.-Colonel S. G. Burrard, R.E.

Earthquakes.

In June, 1897, an earthquake of great severity shook the hills in Assam most severely, and its effects were felt more or less all over India. Calcutta suffered very seriously, numbers of houses being dangerously cracked and a portion of the spire of the cathedral being thrown down. The amount of permanent displacement to which the hills had been subjected was a matter of great interest, and an attempt was made to measure this by re-observing at the principal trigonometrical stations nearest the centre of disturbance. No large instrument was available, but the best in hand at the time was given to an assistant, and he re-observed the horizontal and vertical angles at thirteen stations, fixing the positions of twenty-two and the heights of twenty-five old stations over an area of 1,000 square miles. The results showed that the whole of this area had been affected by the earthquake, so it is impossible to say how much these stations had been displaced in comparison with the unaffected area outside; the average displacement amongst themselves amounts to about 7 feet, whilst the changes in height vary from a subsidence of $4\frac{1}{2}$ feet to an upheaval of 24 feet.

Financial reasons prevented any extension of these interesting observations with a larger and more accurate instrument, so it is much feared that this almost unique opportunity of ascertaining with accuracy the actual displacement of a portion of the earth's surface due to an earthquake will be lost.

On January 22nd, 1898, a total eclipse of the sun took place in India. The Survey Department sent a detachment under Mr. Pope (one of the Assistant Surveyor-Generals) to Dumraon in Bengal, with an equatorially mounted camera; his object was to obtain as good a picture of the corona as possible; his results were excellent. At Sahdol, in Central India, the Astronomer Royal and Prof. Turner erected their instruments; the camp was managed by Survey officers, and I had the pleasure of being present myself, and a most interesting time we had. The observatories were mere grass sheds, but they answered the purpose well enough. Another camp was also in our charge at Pulgaon, where Mr. Newall and Capt. E. H. Hills, R.E., conducted their observations.

Magnetic Surveys.

The latest scientific operation undertaken by the Trigonometrical Branch is a magnetic survey of India and Burmah. In 1899 Capt. H. A. D. Fraser, R.E., who was then in England on furlough, was deputed to consult Prof. Rücker, and to make a study of the subject, and to obtain suitable instruments. In December, 1900, Capt. Fraser returned to India and took charge of the work. The general scheme is to determine the declination, dip, and intensity at points between 30 and 40 miles apart. At Colába, Kodaikánal, Dehra Dun, Madhupur, and Rangoon permanent magnetic observatories will be established and self-recording instruments installed.

Topographical Surveys (*Map* II.).

Having thus given a brief outline of the growth and progress of the more scientific branch of the Department, let us take a glance at the topographical surveys. The first attempt at a regular detailed survey was made by Colonel Colin Mackenzie, who from 1790 to 1809 was employed in making maps of part of the Deccan, and was then made Surveyor-General of Madras; his work, which comprised an area of 40,000 square miles, was embodied in one general and seven provincial maps. His details were based on triangulation, which was independent of that of Lambton, with whom it appears he did not work harmoniously. I am unable to tell you what his system of detail survey was. In 1816 he was removed to Calcutta, and was made Surveyor-General of India, which office he held till 1821, when he was succeeded temporarily by Colonel Hodgson until Colonel Blacker took up the appointment in 1823. During this first period of the topographical surveys, maps were made of all the districts south of the Kistna River, mostly based on Lambton's triangulation. At about the same time surveys were made of the Ganges, first from Hardwar to Allahabad, and afterwards northwards nearly to its source at Gangotri. Route surveys were also made in Oudh and Rohilkund; then followed rough maps of the Himalayas between the Ganges and the Sutlej and of the provinces of Kumaon and Garhwal, as well as a map of Bandelkund and a route survey of Bhopal and Barsia, in Central India. The Sunderbands were also surveyed in 1812–18 by two young brothers Morrieson, who related how they were much annoyed by tigers and alligators, and how a tiger sprang out of a tree just over their instrument whilst they were in the act of observing; also how their instrument vibrated from the shaking of the ground caused by the tread of huge monsters in the jungle. On the Bombay side the most important work consisted of a careful survey with compass and perambulator of Gujerat and Katiawar.

When Sir George Everest was made Surveyor-General as well as Superintendent of the Great Trigonometrical Survey in 1830, his attention was so much taken up with the more scientific part of the work that the geographical delineation of the country somewhat languished. Yet considerable progress was made, more especially in the Revenue surveys, of which I shall speak presently. Topographical surveys were made of the wild country about the sources of the Nerbudda River up to Jubbulpore, and a survey was commenced to connect Assam with the maps already made of the Ganges in Lower Bengal; this was, however, suddenly suspended by the orders of Government. The breaking out of the first Burmese war had given an opportunity of gaining much information in the direction of the N.E. Frontier of Bengal; and Capt. Bedford, with Lieuts. Wilcox and Burlton, had been sent in 1825 to explore the Brahmaputra to its source; Burlton made a survey as far as Sudiya, Bedford made journeys up the Dihong and Dibong Rivers until he was stopped by wild tribes, and Wilcox succeeded in making one excursion beyond the frontier up the Brahmaputra valley, and on another occasion penetrated to the banks of the Irrawaddy. Meanwhile the survey of the Nizam's territory, based on Lambton's triangulation, was progressing systematically and steadily; in Madras some districts were re-surveyed and others were completed; in Bombay some compass surveys, not based on triangulation, were made, but they were of little value.

From 1843 to 1861, during the administration of Sir Andrew Waugh, great progress was made in topographical surveys, the most interesting and valuable being undoubtedly those of the Sind Sagar District in the Punjab by Capt. D. G. Robinson, R.E., and of Kashmir by Capt. T. G. Montgomerie, R.E. The former is on the 1-inch scale and has been published in 28 large sheets, comprising the whole of Rawal Pindi and Jhelum and the hilly parts of Shahpur and Liah, covering an area of 10,554 square miles; it was completed in 8 years. It was based on triangulation, and the detail was filled in with great accuracy and fidelity on the plane table by men trained by Robinson himself; the hills are shown by brush shading and the maps are beautifully executed. On the completion of this Major Robinson commenced the survey of Central India; he may be looked upon as the father of the topographical system as it now exists, and is therefore entitled to more than a mere passing notice. He introduced the present accurate method of using the plane table and of delineating the ground, which, with very small modifications, is still in use, and in suitable country is never likely to be superseded. He trained almost all the best men who held charge of parties for some 15 years after his retirement from the Department in 1865. He officiated as Superintendent of the Great Trigonometrical Survey in 1863–64, and as Deputy Surveyor-General, Revenue Branch, in 1865; but in that year he was invited to take the appointment of Director of Telegraphs, which he accepted, and held till his death in 1877.

The Kashmir survey under Montgomerie was made in a similar way, but on half the scale, and parts of it were sketchy owing to the inaccessibility of the country, which rendered it impossible to climb to every peak or along every ridge to get in the details with rigorous accuracy.

In 1861, when Colonel H. L. Thuillier succeeded Sir Andrew Waugh as Surveyor-General, topographical parties were at work in Central India, in the Nizam's territory, in Ganjam, and in Chota Nagpur. The following year a fifth was added to survey Rewah; a sixth was soon after organized to map the forest-clad hills of Assam, Naugong, and North Cachar; whilst a seventh started work in Rajputana. At the same time that the country in general was thus being delineated on the 1-inch scale, large scale plans of the most important towns and forts were prepared. In 1871 a party was sent to the hill tracts of Assam and Manipur, the object being to demarcate and survey that portion of the Naga Hills which is contiguous to Manipur, and to explore the extreme frontier along the Patkoi Range as far eastward as possible. This part of India presents immense natural difficulties, which are greatly increased by the hostility of the tribes which inhabit it; Government was constantly having to send punitive expeditions against them, and much geographical information was obtained by the survey officers who accompanied them. But even when they were working in places where peace was supposed to reign our parties were always accompanied by strong escorts, and not without good reason, as the following instances will show. On one occasion Capt. W. F. Badgley, I.S.C., who was in charge of the party, was treacherously attacked by Nagas, who murdered Capt. Holcombe (Political Officer) and 80 natives, besides severely wounding Capt. Badgley and 51 natives, some of whom died afterwards; it was entirely due to his pluck and energy that the remainder succeeded in extricating themselves. Again, Lieut. W. G. Woodthorpe, R.E., accompanied by Capt. Butler as Political Officer, entered the Naga Hills with a detachment; they had hardly commenced work when they were attacked by the inhabitants of a large village, whom they defeated; this fortunately had the effect of inducing the surrounding villages to send in friendly deputations.

In 1874 a party was formed out of that which had been working in Rajputana to commence the survey of Mysore; here they were working over the ground originally triangulated by Lambton, and traces of his old stations were in some cases found. This survey was completed in 11 years.

Since that time there have been generally six to eight parties at work in India and Burmah; in the latter country some excellent reconnoitring work was done by Capt. J. R. Hobday, I.S.C., during the war in 1886 and in the years immediately succeeding it; subsequently, regular topographical parties have been at work there, and now there are no less than four working on the 1-inch scale. A great deal of most valuable sketching has been done in that country by small detachments, under Major F. B. Longe, R.E. and Capt. T. F. B. Renny-Tailyour, R.E., who were deputed to accompany the Political Officer sent to demarcate the boundary between Burmah and China. On these occasions the dilatoriness of the Chinese caused many delays; but this rather assisted the surveyors, who thus often had time to do more than they otherwise would have been able to accomplish. Instruments had been supplied to the Chinese for their use, but none of them had the slightest knowledge of surveying, and so they were never used. An amusing thing was the way the Chinese imitated our officers in all they did; at first they had no flag, but they very soon hoisted one, with the Chinese Commissioner's name in very large letters; if our officers went out for a ride, a riding party from the Chinese camp was soon seen setting out; revolver practice on our part was followed by shots in their camp; the Chinese soldiers took to saluting like our sepoys; and so on. Hurried though these reconnaissances necessarily were, they were excellent of their kind, and were all based on triangulation.

The name of Woodthorpe, of the Royal Engineers, will long be remembered in Assam and on the extreme N.E. Frontier, as for many years he was reconnoitring and surveying in those wild tracts. Almost his whole time in the Department was passed more or less on what may, without exaggeration, be called active service. In his first four years he was attached to three different expeditionary forces; he was with the Kuram column in the Afghan War, and he accompanied Lord Roberts on his famous march from Kabul to Kandahar; on this occasion he received the thanks of the Governor-General in Council and of the Secretary of State for India, and was made brevet lieut.-colonel. He then returned to the N.E. Frontier and visited the Bor-Kamti country with Major Macgregor, reaching the banks of the western branch of the Irrawaddy; on their return the whole party was very nearly lost, owing to the flooding of the rivers in front of them, whilst behind them were many marches of inhospitable country. Notwithstanding the exposure he had undergone during this journey, he took no rest, but went on special duty to the opposite corner of British territory, viz., to Gilgit; the change from the damp malarious jungles of the N.E. to the dry and bracing climate of the mountainous regions on the N.W. did him good; after a year he returned once again to the east, and went in charge of a survey party with a military column from Assam, *viâ* Manipur, into the Chindwin Valley, in Upper Burmah, bringing back sketch maps of a very large area of previously unknown country. He was made a C.B. and became a major-general, but died in May, 1898, when officiating as Deputy Surveyor-General, to the regret of all who knew him.

But it must not be supposed that all the luck was confined to one man; during the Afghan War of 1879 to 1881, 13 military and several civilian officers of the Department were attached to the different columns, and many of them obtained brevet rank, one, Capt. (now General) E. P. Leach, R.E., winning the Victoria Cross. It is hard work keeping up a reconnaissance with an army on the march, as I can say from personal experience; it almost always entails not only constant tramping all day up and down the neighbouring hills as far as possible, but also work which has to be done at night, such as inking in the day's work or computing out the observations if triangulation has been possible, or (not infrequently) astronomical observations for latitude or azimuth. Native surveyors greatly assist at such times, as they can run plane-table traverses along the actual route, whilst the officer can devote his time to triangulating and sketching among the surrounding hills. Some 39,500 square miles in Afghanistan and 7,800 in Baluchistan were added to our geographical knowledge during this war.

In 1884 three officers, Major (now Colonel Sir) T. H. Holdich, R.E., Capt. St. G. C. Gore, R.E., and Lieut. M. G. Talbot, R.E., were deputed to accompany Lieut.-Colonel (now Sir) West Ridgeway on the Afghan Boundary Commission. The two junior officers started a triangulation from the stations fixed during the war, and carried it on, with great difficulty on account of the haze, as far as the Helmund; after that it was impossible to keep up an unbroken chain, and each day's halting place was fixed by latitude observations, and, whenever possible, triangulation was again started on short measured bases; at the same time a plane table survey on the ¼-inch scale, embracing an area of country averaging 20 miles in width, was made. In this way Kuhsan was reached, a distance of 310 miles being covered in 19 days. From there several small series of triangles, depending on detached bases, were run in different directions; astronomical checks were introduced, in which our officers were assisted by the Russian officer, who had a higher class of instrument than our 6-inch theodolite. On the basis of this triangulation all the topography was executed, whether by the Russian surveyors on a comparatively large scale along the boundary, or by our survey officers and native surveyors, who not only took up their share of the boundary work, but executed on a smaller scale a reconnaissance of a vast area in Persia and Afghanistan, amounting to over 110,000 square miles. The general scale was 4 miles to the inch, but this at times had to be reduced to half, so as to allow of a sufficient number of fixed points being plotted on the plane table.

In the same way that the name of Woodthorpe will ever be connected with the N.E. Frontier, so will the name of Holdich be connected with that on the N.W.; in addition to his services in that part of the world, he was in the Bhutan Campaign, and also accompanied the expedition to Abyssinia; he is now a C.B. and K.C.I.E., and quite recently has been made a K.C.M.G. for his services connected with the Chili-Argentine Boundary.

Such records as these will show you that there are as good opportunities for an officer to distinguish himself in the Survey Department as in any other in the world.

Whilst the Afghan War was occupying a large number of our officers in the extreme N.W., on the N.E. Frontier Lieut. H. J. Harman, R.E., was making a survey of Sikkim, a Native State north of the well-known sanatorium of Darjeeling; he personally undertook the northern part amongst the gigantic mountains east of Kanchanjinga, the second highest mountain in the world. He proceeded in the first place to the ranges on the frontier of Thibet, hoping to survey them in the brief interval between the rainy season and the setting in of the winter with its heavy snowfalls. When ascending the

Donkia La Pass on the boundary his feet were so badly frostbitten that he eventually lost several of his toes; but with great pluck and energy he persevered, going as best he could on the backs of coolies, ponies, or on crutches. He also visited the Kangra Lama Pass, and penetrated into parts of Sikkim which no European had previously explored. He was in Sikkim about $3\frac{1}{2}$ months, during which he surveyed 1,000 square miles on the $\frac{1}{4}$-inch scale; he greatly overtaxed himself in this arduous work, and his health broke down, forcing him to retire from the service; he lived to join his family in Italy, but died soon after.

In telling you of the adventurous expeditions and good services of our military officers I must not omit to mention what some of our civilian members have done. In the early part of the Afghan War, Mr. G. B. Scott, whilst reconnoitring the hills north of the Khyber Pass, in the neighbourhood of Fort Michni, was attacked by a considerable number of Mohmands; with great courage and coolness he kept his men together and steadily retreated, fighting every inch of the way for some miles; the fight, which at one time was actually hand to hand, lasted the whole afternoon, but he took his party back in safety, with the exception of one naik (corporal) and one sepoy killed and wounded. He had already received a sword of honour and an honorarium from the Government of the Punjab for conspicuous gallantry in 1868, and he now received another honorarium on this occasion.

In 1883 Mr. W. W. McNair, accompanied by a native explorer, started on a most hazardous journey into Kafiristan; he assumed the dress and disguise of a native doctor, shaving his head and staining his face and hands. The party consisted of 40 men in all, with 15 baggage animals; among the goods McNair stowed away some small instruments and a specially constructed plane table, the paper on which could be quickly slipped inside, and the plane table became a doctor's prescription book. On one occasion he was very nearly detected by four men armed with matchlocks, but in a moment the ruler was slipped up his long loose sleeve, and the men found nothing but a doctor hunting for roots. A report having reached the ruler of Chitral that two Europeans were travelling about the country in disguise, he sent for McNair and compelled him to return. For the work he did during this expedition the Royal Geographical Society awarded him the Murchison Grant.

About the same time Mr. T. E. M. Claudius undertook an expedition less ambitious than this, but still one full of danger and requiring great audacity, combined with coolness and readiness of resource. He disguised himself and advanced up the valley of the Bar Marai, and ascended a lofty peak commanding the Urukzai Tirah; he was without companions or servants of any kind, and relied solely on the protection of the chiefs; his equipment was a small plane table, which took to pieces. Fraternizing with the people, he obtained all the opportunities he required, and returned in safety. In a second attempt in another valley his disguise was detected, and he was turned back.

Besides the regular topographical parties, which usually work on the 1-inch scale, there are others which make special surveys of the valuable forest lands which are found in all parts of India; these are generally on the 4-inch scale, but in some places the 8-inch and, in certain small areas, even the 16-inch is used. Originally a special branch, to work in the Bengal Presidency, was organized under the Director-General of Forests, but subject to inspection by the Surveyor-General, and for many years it did good work; but quite recently it has been amalgamated with the Department, its programme being laid down by the Director-General of Forests. Now all the surveys in India, except the Revenue Surveys of Bombay and Madras, are united in one department.

I have thus far only spoken of the field duties of a topographical party, which are performed during the cold season, and continued till the weather becomes so hot as to endanger the health of the men. Roughly speaking, the field season extends from the 1st of November to the end of April; at its close all natives who have done good work, and who are not wanted for the office duties, are given leave up to the commencement of the next field season, with a promise of half pay or less, according to their deserts, and on condition that they return punctually on the day appointed. The remainder of the party then proceed to their recess station, which is always situated at the most healthy station within reach, generally in the Himalayas. There being no suitable place in Burmah, all the topographical parties from there recess at Bangalore, which is, I think, the best station in India not a hill station. The principal recess duties are to compute out the triangulation and to fair draw the field sheets in a style suitable for photozincography. It is generally found that the office duties occupy the whole time during which the party is in recess. Each party must have amongst its surveyors draftsmen of sufficient skill to prepare the fair maps, and all must be more or less conversant with the ordinary computations.

Up to 1878 General Sir Henry L. Thuillier, R.A., was Surveyor-General and superintended the topographical surveys; he was succeeded by General J. T. Walker, R.E., who, for the five years from 1878 to 1883, administered both the trigonometrical and topographical surveys, in addition to carrying on the duties of Surveyor-General. On his retirement Colonel G. C. Depree, I.S.C., was appointed Surveyor-General and Deputy Surveyor-General of Topographical Surveys, which posts he held till 1887, when he died. Colonel Sir Henry R. Thuillier, R.E., son of the General, was then made Surveyor-General, and took charge of the topographical surveys till 1895, when he retired. I had the honour of succeeding him in the same appointments, which I held till 1899, when Colonel St. G. C. Gore, R.E., was appointed.

During the ten years from 1890 to 1900 the area accurately surveyed in India on the scales of $\frac{1}{2}$ inch, 1 inch, and 2 inches to the mile amounted to 146,700 square miles, in addition to nearly 40,000 on larger scales. During the same time upwards of 700,000 square miles of reconnaissance and small scale geographical surveys were executed in the neighbouring countries.

Revenue Surveys (*Map* II.).

The Revenue surveys were commenced in the N.W. Provinces in 1823 under Colonel Valentine Blacker, who was then Surveyor-General. Their chief object was to lay down the correct boundaries of villages, to assist in making a land settlement; accuracy of topographical detail was a minor consideration. In addition to the plan of each village, which was on the 4-inch scale, a list of the fields with their measurements was made. Up till 1834 the interior details were fairly well shown, but after that, by an order of Lord Bentinck, a new plan was adopted, introducing economy and rapidity at the expense of quality. The maps were to delineate boundaries and village sites, whilst the roads and drainage lines were to be only roughly outlined. Moreover, they preceded the trigonometrical survey, and no subsequent connection was made.

In 1847 Major (now General Sir) Henry Thuillier was made Deputy Surveyor-General in Calcutta, under Sir Andrew Waugh, and great improvements were made in Revenue surveys by him. They were conducted in the following way:—The settlement officer marked the boundaries of Parganas (as certain groups of villages are termed), and furnished the surveyor with a rough sketch map of the same; with the help of this map trained native surveyors ran a theodolite traverse closely following the boundary, all measurements being entered in a field book; the interior village boundaries were treated in the same way. Thus a correct skeleton was made which afforded a check on the field measurements; the topographical details were filled in on a plane table; the traverses were connected with the trigonometrical stations wherever they were met with.

Rapid progress was now made on a scientific system, and Revenue surveys were gradually undertaken in the Punjab, Nagpur, Oudh, and the Lower Provinces, in fact all over the Bengal Presidency except the N.W. Provinces, which had been surveyed in the rough way I have alluded to. Most of the original village plans were destroyed in the Mutiny, only those of twelve districts being saved. When the time arrived for a second settlement of these provinces, it was proposed to again dispense with an accurate survey, as it was argued that the measurement of the fields by natives was all that was required, and if topographical detail were wanted it could be entered by topographical surveyors. As a matter of fact, these field measurements, having no fixed points to depend on, necessarily accumulated large errors, amounting sometimes to as much as 7 per cent. in area. Fortunately such a short-sighted policy was not carried out, and in 1871–72 the whole system was revolutionized, and the cadastral system of field by field surveys was introduced, and has been in use ever since.

By this system theodolite traverses are run close to the boundaries as before; these are plotted village by village on the 16-inch scale and mounted on a plane table; the fields are then carefully surveyed in minute detail by a chain survey. The theodolite stations of the traverse lines, or a large proportion of them, are marked permanently by stones, bricks, burnt clay pipes filled with charcoal, or some cheap indestructible material sunk in the ground and covered with mounds of earth; the headmen of the villages are made responsible for their preservation. By this means it is hoped that the accurate skeleton on which each map depends will always be found ready for use hereafter in revision surveys. Each field or bit of waste land, including the village site, is numbered on the map, and the area is taken out by a planimeter; the total is then compared with the area as found by calculation from the exterior traverse line. In the case of disagreement the areas obtained by the planimeter are taken out again. The field survey is checked by chain lines run between fixed points across the maps themselves by Europeans and native inspectors, and by independent lines recorded in a field book, the map remaining in the hands of the European in charge. All appreciable differences are shown in red ink, and if these exceed a certain amount, a re-survey is made. The men who run the traverses are members of the Department, but the field surveys are made by men trained by the Department, but paid by contract. The system of chain survey is easily learnt by natives, and the results are excellent. These field maps are in most provinces photo-zincographed, and a few copies are struck off, a certain number of which go to the Local Government, the remainder being kept for sale. This is the system now in use in the Department, and it is admirably suited to the country. In the Madras and Bombay Presidencies they have always conducted their own Revenue surveys, and I do not know exactly their systems.

About 15 years ago a large-scale map of Calcutta was commenced. No such survey of the town had been made since 1847–49, when a topographical survey on the scale of 100 feet to the inch was made by Mr. Simms, C.E.; on this was added a survey of the boundaries of holdings by Mr. Heysham, in 1851 to 1855; but this had become out of date, and a newer map on a larger scale was much wanted. One was started in 1886 on the scale of 50 feet to the inch, but owing to the dilatoriness of the authorities in demarcating the boundaries of holdings it was not completed till 1894. It was executed with the utmost care and in great detail, and is being kept up to date, at a small annual expense, by a native surveyor attached to the headquarters office, whose duty it is to enter, on copies of the original sheets, all alterations or additions as they occur, these being pointed out to him by the municipal authorities without whose consent no changes in the town can be made. From these large scale sheets an engraved map on the 16-inch scale has been made.

Instruments.

In Lambton's time the instruments, though the best that could then be procured, were not only inferior to those made nowadays, but they were much larger and heavier (*Fig.* 10, *Plate* I.); moreover, there was no means of getting them repaired. It was the custom for officers to supply their own instruments; Colonel Hodgson had instruments and books to the value of £1,300, and nothing belonging to Government, as he considered this to be better than trusting to the only alternative, the supply by contract, for he declared that the instruments that had been sent out to the Revenue survey in 1821 were not such that a good surveyor would consent to use. Everest saw these evils, and, whilst in England, personally superintended every detail in the construction of his own instruments; and when he returned to India in 1830 he took with him an accomplished maker (Mr. Barrow), and started a mathematical instrument manufactory in Calcutta. The second 36-inch theodolite, known as the Barrow theodolite, was made here under Everest's direction; the graduation was executed by Barrow, and the instrument was built of old musket barrels and parts of Lambton's theodolite that had been damaged. Barrow's successor was a native of Arcot, Syud Mohsin by name, who, though he could not write English, would have taken his place amongst European makers. Since his death the head mechanic has, I think, always been supplied from Cooke's establishment at York. In 1862 Colonel Strange, who had himself been a member of the Great Trigonometrical Survey for 13 years, was entrusted by the Secretary of State for India to design and superintend the construction of a set of geodetical and astronomical instruments for the trigonometrical survey, and in the following year he was appointed to examine and test all instruments sent to India. For the testing of these an observatory was built at Lambeth. The special instruments designed by Colonel Strange consisted of the following:—A 36-inch theodolite and two zenith sectors by Theobald & Synge; two 5-foot transit instruments and two smaller ones by Cooke; two 12-inch vertical circles by Repsold of Hamburg; two galvanic chronographs for registering transit observations, by Secretan & Hardy of Paris; and three astronomical clocks, by Frodsham. In more recent years two 12-inch theodolites have been added (*Plate* II.), which, owing to the greater perfection of the graduating machinery of the present day, are very nearly, if not quite, equal to the old 36-inch theodolite, and are about a quarter of the weight. The instruments for recording the tides, for determining the differences of longitude by the electric telegraph and, lastly, the magnetic instruments have all been supplied in more recent years. The Mathematical Instrument Office at Calcutta does not attempt to make large instruments; it would not pay to do so even if the requisite appliances and skill were available, but it accomplishes an immense amount of excellent work in making the smaller kinds, and in repairing or converting old and obsolete theodolites and levels into ones of more modern patterns, making them as good as new. In the report for 1899—1900 it is stated that 140 old levels and 98 old theodolites were converted into serviceable instruments, and 21,577 instruments of all kinds, great and small, were manufactured; 57,160 instruments were received into store, and 59,743 were issued; from England 12,082 were received. I should explain that all these instruments do not go to the Survey Department, as the mathematical instrument office supplies all the other Government departments in India as well.

Figs. 1 to 3, *Plate* III., show some of the instruments in use in ancient times, before the invention of the telescope; from pictures only it is difficult to understand how they were used, but surprisingly good results were obtained from them. They belong to the ancient observatory at Jeypore, in Rajputana.

Survey Department Offices.

In conclusion, I should like to say a few words about the other headquarters offices in Calcutta and Dehra Dun. Five-and-twenty years ago there were no special buildings for the Department; the Surveyor-General held his office in one house, the Deputy Surveyor-General of the Revenue Branch in another, the Mathematical Instrument office was in a third, whilst the Photo, Litho, and Engraving offices were located in three separate houses; none of these had been built to suit the purposes for which they were used, and were ill adapted and badly lighted. This became so inconvenient that Government decided to erect suitable buildings, specially designed to suit each branch. These, which were three in number, were all completed by 1888; the largest of the three is occupied by the Surveyor-General and Deputy Surveyor-General, with their numerous clerks and assistants, who occupy the first floor, whilst above them is a large, well-lighted drawing office, and on the ground floor the printed and original maps are stored; the Engraving office is also in this building. The central building is occupied by the Photo, and Litho, and Letterpress-printing offices. The third contains the Mathematical Instrument office. To assist the Surveyor-General and his deputy there are three Assistant Surveyor-Generals, each of whom is in charge of one or more of the different sections into which the whole is divided.

The main duties of the Drawing office are to compile and draw all general maps of districts, provinces, or of India as a whole; to prepare brush-shaded copies of the field sheets on the $\frac{1}{4}$-inch scale for the engravers; to examine all the fair maps received from the field parties, to see that they have been suitably prepared for photozincography; and to examine and pass all the photozinco proofs of all maps before publication. But in addition to these there is an immense amount of miscellaneous work, not only for the Department itself, but for Government generally, which often so hampers the draftsmen that the general maps have to be put on one side at times for want of hands to draw them.

The Engraving office was started in 1869 by General Sir Henry L. Thuillier, who engaged a staff of trained engravers while he was in England. Its principal work is to cut on copper the sheets of the $\frac{1}{4}$-inch atlas of India, and to keep up to date as far as possible those already cut; and to engrave maps of the provinces on the 16-mile and of India as a whole on the 32-mile and smaller scales. The sheets of the atlas are being engraved as the survey parties send in reliable material; in many cases sheets have been published based on old and incorrect work; these are all being re-engraved from modern surveys; on the completed ones new railways and roads have to be entered. The 32-mile map of India is gradually being prepared in the same way; meanwhile temporary editions are issued by transferring the engraved portions on to stone and filling in the blanks by lithography. Quite recently a new engraved map of "India and Adjacent Countries" on the scale of $\frac{1}{1000000}$ has been started.

When I first joined the Department in 1863 there was but a very small Lithographic office, altogether too weak to cope with the work of the Department; hence the topographical maps had to be sent to England for publication, and it was not for many years that any results were received. General Sir Henry L. Thuillier greatly increased the strength of this section; but at best lithography is a slow process, and had we been dependent on that alone the public would have received very little benefit from our labours. Photozincography, however, came to our rescue, and it was introduced into India by Mr. Hennessey, who executed the first photozinco at the Dehra office. Its first appearance in Calcutta was in 1866, and ever since that all cadastral and topographical maps, triangulation charts, etc., have been published by this process; there is still ample work for the Litho office, but it is of a somewhat different nature, and a great deal of it is for other Government departments. As photozincography will not satisfactorily reproduce half-tones, the style of drawing of the field sheets had to be altered, and pen and ink had to be substituted for brush shading; this at first caused great trouble in the field parties, as the draftsmen had to teach themselves an entirely new style. To give an idea of the amount of work done by the publishing offices I will quote a few figures from the report of 1899—1900:—

Of Department maps there were 983 different subjects, of which 99,176 copies were printed; cadastral, 4,942, of which 162,733 were printed; outside departments, 1,534, of which 588,593 were printed; giving a total of 9,459, of which 850,502 were printed.

The actual number of pulls to complete these maps, several being on more than one sheet, was over 1,000,000. General J. Waterhouse, I.S.C., has been closely connected with this most important part of the headquarters offices for many years, and its present high state of efficiency is entirely due to him. He devoted his whole time to introducing new methods and to improving existing ones, so as to be suitable to the pernicious climate of Calcutta. Photo-collotype, photo-etching, photogravure, photo blocks, were all initiated by him. He retired in 1897 after a service of 30 years in the Department, all of which were spent in charge of the publishing branches.

At Dehra Dun is located the office of the Superintendent of the Great Trigonometrical Survey; attached to it is a small Photozinco office; but its most important duty is to compute out the final values of the triangulation and of the astronomical observations. There is also a solar photographic section, by which photos of the sun are taken every day that it is visible; and the results are sent to England to supplement the daily record which is kept of the appearance of the sun. A complete set of meteorological observations is kept there as well. Under the direction of the Superintendent, a school of training for all members of the Department, Europeans as well as natives, has of late years been established. In former days each field party taught its own men; but it was found that this occupied so much of the time of the older hands, and interfered so much with their legitimate duties, that this school was started to enable them to devote their whole time to their field work.

It may not be inappropriate if I give my opinion to those officers of the Royal Engineers who are going out to India as to the desirability of joining the Survey Department. For a young officer who has no objection to steady and somewhat hard work, and has any taste for accuracy and for dealing with delicate instruments, or any turn for practical geodosy or astronomy, I most strongly recommend the Trigonometrical Survey. To the somewhat less scientific I recommend the Topographical Branch, in which I served for 20 years; the last 16 years of service in the Department were spent at the Headquarter offices in Calcutta. I consider that the work in itself is most interesting, for half the year the members spend their time in that pleasantest of all lives, camp life in India, not infrequently having opportunities of seeing countries rarely or perhaps never before seen by Europeans, and as good opportunities of seeing active service as anyone else. Those who are fond of sport are pretty sure to meet with it during the field season, and then, when the weather begins to be unpleasantly hot, they retire to a pleasant station and lead a civilized life by way of a change for six months. Good health, zeal, and energy are absolutely necessary qualifications, and without them I do not recommend anyone to join the Department.

Plates IV. and V. give some examples of the exceedingly interesting country with which the surveyor in India may meet.

LIST OF PLATES.

PLATE I.

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Fig. 1.

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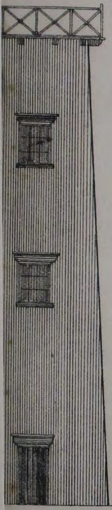

30 Feet

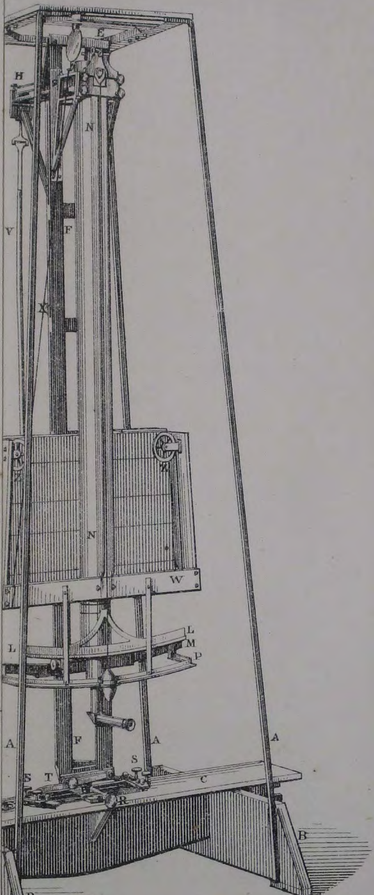

Fig. 10.