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CAPTAIN W. A. GALE, R.E.

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EDITOR'S PREFACE.

THE present Volume (XIX.) of the *Occasional Papers* for 1893 contains ten papers, of which eight are by Officers of the Corps.

Paper II., by Captain J. M. Grierson, R.A., is an interesting account of the German Army, while Colonel J. R. Hogg, R.E. (Paper VI.), contributes an account of the French Port of Bizerta, which appears likely to have considerable influence on future maritime operations in the Mediterranean. Papers III. and IV., Captain Kenyon's Fortification and Major P. T. Buston's Account of the Bridging Operations of the Bengal Sappers and Miners, complete the portion having a bearing on our more military duties; the remaining six being devoted to those of a more purely scientific nature.

Paper VIII., a translation by Major W. H. Chippindall, R.E., of a Graphic Solution for Equations, will be of mathematical interest. Surveying and Astronomy are dealt with in Papers I. and IX. by Professor John Coles, F.R.A.S., and Captain S. C. N. Grant, R.E.; and Building Construction in Papers V. and VII., by Lieutenant G. C. Kemp and Captain G. K. Scott-Moncrieff.

The Volume concludes with an interesting Series of Lectures by Colonel Sir Colin Scott-Moncrieff on Irrigation in Egypt, a work with which his name is most intimately connected, and on which subject no one can speak with greater authority.

W. A. GALE, CAPTAIN, R.E.

Secretary, R.E. Institute, and Editor.

Chatham, September 1st, 1893.

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PAPER I.

THE PRACTICAL USES OF SURVEYING AND ASTRONOMY TO THE EXPLORER.

BY JOHN COLES, F.R.A.S.

(*Map Curator and Instructor in Practical Astronomy and Surveying, Royal Geographical Society*).

LECTURE I.

IN the two lectures which I am about to deliver on "The Practical Uses of Surveying and Astronomy to the Explorer," I propose to bring before your notice the methods and observations by the use of which the best results can be obtained under the circumstances in which an explorer generally finds himself placed, and it will be well to give a few minutes' consideration as to what those circumstances are. In the first place, with the exception of the coast line, which is correctly laid down on the Admiralty charts, he is frequently without any point of departure, the position of which has been definitely fixed in latitude and longitude. Then it is very seldom that he has any person who can assist in surveying or observing, or whom he can consult when in doubt on any scientific subject, and lastly, it not unfrequently happens that he is prevented by the hostility of natives from proceeding in the direction he wishes to travel, and has, therefore, to arrive at his destination by a roundabout way. The explorer has many other difficulties to overcome, but those which I have mentioned are sufficient to show that he must entirely depend on his own resources, and that he must, in the first place, before making a start, be able to fix his position in latitude and longitude. I shall, therefore, reverse what might be considered the natural order of things, and commence my lecture with some observations on the methods most convenient to explorers for fixing their positions by astronomical observations.

In proceeding to deal with this subject, I would say that before any person can engage intelligently in practical astronomy, it is absolutely necessary that he should have a correct knowledge of the circles of the heavens. Without this he can only proceed in a rule-of-thumb sort of way, which will sooner or later land him in error. I will, therefore, by way of refreshing your memory, call attention to *Fig*. 1, which is a projection of the celestial sphere on the plane of the meridian.

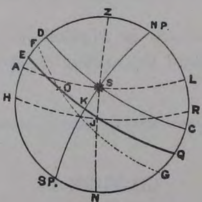

Fig. 1.

NP, Q, SP, and E is the meridian, NP the north pole, SP the south pole, EQ the equator, DC is a parallel of declination, KS is the declination of a heavenly body at S. O is the first point of *Aries* from which the right ascension OK is measured eastward from 0hrs. to 24hrs. FG is the ecliptic, ENPK is the hour angle, NPS the north polar distance, Z the zenith, N nadir, HR the horizon, ASL a parallel of altitude. RJ is the azimuth of the heavenly body at S, JS is its altitude, ZS its zenith distance, EZ the latitude, and ZNP the co-latitude.

I will next shortly notice the corrections that have to be made in the observed altitude. These, in the case of the sun, are: index error, refraction, semi-diameter and parallax.

It is well known by various experiments that the rays of light deviate from their rectilinear course in passing obliquely out of one medium into another of a different density; and if the density of the latter medium continually increases, the rays of light passing through it will deviate more and more from the right lines in which they were projected towards the perpendicular of the surface of the medium. The ray before entering the second medium is called the incident ray; after it enters the second medium it is called the refracted ray, and the difference between the two is the refraction.

To illustrate this, let MN in *Fig.* 2 represent the strata of the

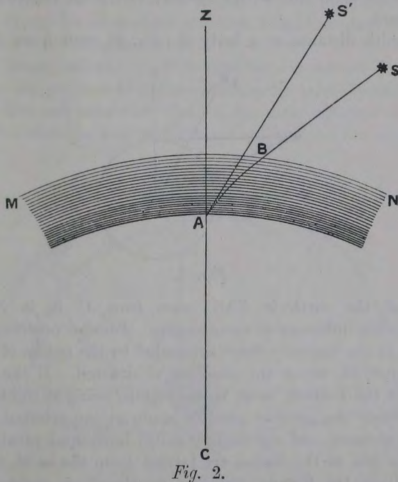

Fig. 2.

earth's atmosphere; SB a ray from the star S, entering the atmosphere at B, where it is bent into the curve BA, and as the last direction of the ray is that of a tangent to its curved path at the eye of the observer, the apparent direction of the star will be AS′, and the refraction will be the difference of the lines AS′ and BS. Thus it will be seen that refraction always makes a heavenly body appear higher than it really is, and the correction is, therefore, a minus one. At the zenith, refraction is nothing; the less the altitude, the more obliquely the rays enter the atmosphere, and the greater will be the refraction, which is, therefore, greatest at the horizon. As regards the correction for the sun's semi-diameter, it will be sufficient to say that it is taken from the *Nautical Almanac* and added or subtracted to the observed altitude, according to whether the lower or upper limb has been observed.

The parallax of a heavenly body is in general terms the angle between two straight lines drawn to the body from different points; but in practical astronomy *geocentric* parallax is alone considered, and this is the difference between the apparent positions of a heavenly body as seen from the earth's surface, and from its centre at the same instant.

The zenith distance of a body S (*Fig.* 3) seen from A on the

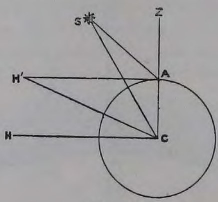

Fig. 3.

surface of the earth is ZAS; seen from C it is ZCS, and parallax is the difference of these angles. *Parallax in altitude* is then the angle at the heavenly body subtended by the radius of the earth at the point on which the observer is situated. If the heavenly body is in the horizon, as at H, the radius, being at right angles to AH, subtends the greatest possible angle at the celestial body for the same distance, and the angle is called horizontal parallax. The parallax is less as the bodies are farther from the earth, as will be evident from the figure. Parallax is, therefore, greatest at the horizon and disappears at the zenith, and as we are supposed to observe from the earth's centre, parallax always makes a body appear lower than it really is, therefore, the correction is a plus quantity.

So far I have been speaking of corrections to be applied to the observed altitudes of the sun. The only corrections for a star are index error and refraction, which latter affects all kinds of astronomical observations so far as altitude is concerned. Stars appear as mere points without diameters, and are all so immensely distant from the earth that they are not affected by parallax.

Though a planet, as seen in the inverting telescope of a sextant, has often a sensible disc, and, therefore, a diameter, it is much more usual, and, in my opinion, better, when observing one of these with a sextant, to make the two images coincide rather than attempt a contact. A planet, being so much nearer to the earth than the stars, is affected by parallax. Its horizontal parallax is given in the *Nautical Almanac*, and from this the parallax in altitude is deduced. Where an artificial horizon is used, the observed altitude must be halved, as reflection doubles the angle. I have not referred to the moon, as, except for such observations as I shall mention in my next lecture, it is not a suitable object.

Having thus disposed of this preliminary matter, I will now proceed to the subject of fixing positions by astronomical observations, the first and easiest of which is the determination of latitude by meridian altitude, and with the aid of *Fig.* 4 we can see that this

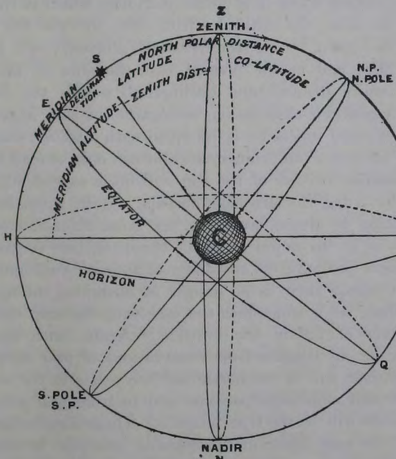

Fig. 4.

is a very simple operation. In the first place, we have the fact that a heavenly body attains its greatest altitude when on the meridian above the pole. We also know that the elevation of the pole above the horizon is equal to the latitude of the place. Now, as we cannot see the pole of the heavens, and, therefore, are unable to observe its altitude, we must find some other angle equal to its altitude above the horizon that we can measure, which we do in the following manner :—*Fig.* 4 is drawn on the plane of the celestial meridian, and you will observe that the horizon is at right angles to the zenith, and that the equator is also at right angles to the pole; therefore, these two angles are equal one to another. Then we may say that the angle ZCQ is equal to the angle NP, C, H, and we, therefore, strike out Z, C, NP, the co-latitude, which is common to both. Again, we see the angles RCQ and ECH are equal to one another because they are vertical and opposite ; we may, therefore, also strike them out, and we have the angle ZCE equal to NP, C, R, which is equal to the latitude of the place. Now, with a sextant or other angular measuring instrument, we observe the altitude of the heavenly body S above the horizon when it is on the meridian, which is the angle HCS. If we take the altitude from 90°, we get the zenith distance SCZ. Then, from the *Nautical Almanac*, we get the declination ECS, and in the present case the sum of these two angles (the zenith distance and declination) equals the latitude. Within the tropics this observation, as regards the sun, is not available for the explorer unless he is provided with a transit theodolite or prismatic sextant, as an ordinary sextant can only be read to 145°, while the meridian altitude of the sun will often exceed 80°, which is doubled by using the artificial horizon. With stars, however, this observation is always available, as, from their number, the observer has it in his power to select those that are conveniently situated. Stars also have the advantage of appearing as mere points, and for that reason there is no danger of mistaking the upper for the lower limb, as is sometimes the case with the sun, the result being an error of 32′ in the latitude. Again, with stars the explorer can fix his latitude from observations of two stars which pass the meridian, one to the north, and the other to the south of him ; and as this eliminates personal and instrumental errors, the mean of results will be the true latitude. These observations may be taken at the same place at considerable intervals between the two stars' meridian passage, and provided no great change has occurred in the meteorological conditions, the results will be satisfactory. There is, indeed, no better way by which an explorer can fix his latitude than by north and south stars. Excellent results are also obtained by taking circum-meridian observations, *i.e.*, sets of altitudes on either or both sides of the meridian, and noting the local time corresponding to each altitude; for this, however, the local time must be accurately known. A convenient method of reducing this observation will be found in the Royal Geographical Society's *Hints to Travellers*, sixth edition, pp. 165—166. If the explorer should be in northern latitude, outside the tropic, the Pole Star can at all times be used to find his latitude, and there is no better method of computing the latitude from such observations than that given in the *Nautical Almanac*.

It may possibly be said that though star observations have some considerable advantages over those of the sun, they require a previous acquaintance with the relative positions and appearance of the stars themselves which a great many explorers do not possess, and that even in cases where some such knowledge has been acquired in the northern hemisphere, it is of but little service when the field of exploration is in the southern hemisphere, where a new set of stars appear, and where the northern constellations visible are, so to speak, turned upside down. It cannot, of course, be doubted that such a previous knowledge of the stars as I have referred to would be extremely useful, but it is by no means indispensable, as any star of the first or second magnitude can easily be identified when on, or near, the meridian in the following manner. We, of course, know that the celestial meridian is an imaginary circle passing through the zenith and the north and south points of the horizon, and we must, therefore, look for a star at culmination somewhere on that circle. For example, if we take Chatham this evening, if at about half-past six we were to look to the south we would see a star easily distinguished from the others near it by its superior brightness, and we could roughly estimate its altitude to be about 55° above the horizontal plane. If we had any doubt on the subject, it would be a very easy matter to measure its altitude with a theodolite or sextant. Now, by referring to *Fig.* 4, we see that the angle subtended by the celestial equator and the horizontal plane is equal to the co-latitude, which at Chatham we may take, in round numbers, as being 38° 35′, and the difference between this and the star's altitude would be 16° 25′, which would, of course, be the star's declination north of the celestial equator. If we were to look in the mean places of stars in the *Nautical Almanac* for the nearest given declination to this, we would find opposite to it α Tauri (*Aldebaran*), but in order to make quite sure that it was that star (and not another with nearly the same declination), by subtracting the sidereal time at the preceding noon from its right ascension (adding 24 hours to it if necessary), the result will be the approximate mean time of its meridian passage. It is not, however, likely that a star of the first magnitude would be mistaken for one less brilliant. Having found the name of this star, it would be a very easy matter, with a star map, and taking this star as a starting point, to find the names and relative positions of others of the first and second magnitudes.

With the aid of the approximate times of the meridian passages of stars, which I have given in the Royal Geographical Society's *Hints to Travellers*, and the star maps that work contains, on which I have coloured all the *Nautical Almanac* stars red, it is even easier to find the names and position of stars, as we have simply to consult the tables, and then, at the time indicated, look to the north or south, as the case may be, for the star. I have dwelt at some length on this subject, as I have frequently found that the supposed difficulty of recognizing stars has prevented some explorers from attempting star observation.

When the weather is overcast, it is not advisable to trust to the chance of getting meridian altitudes, and should the clouds clear away for a short interval, the explorer should make sure of his latitudes by taking simultaneous altitudes of two stars. It is, of course, obvious that one person cannot observe the altitudes of two stars at the same instant, but he can reduce the altitude of the first, to the time when the second was taken, in the following manner:—Take the altitude of the star which is farthest from the meridian, then the altitude of the other star, and lastly that of the first one again, noting the times of each observation by a watch that has a second hand. Then, as the altitude of the first star is proportional to the time elapsed in the interval, the correction to be applied to its observed altitude can be found by direct proportion, and *Fig.* 5 illustrates the manner in which the co-latitude is computed.

Let NHSO be the rational horizon, NS the meridian, Z the zenith, and P the pole of the heavens, W and E the places of two fixed stars. Then, supposing the altitudes of the stars W and E to be observed in the manner already described, we know ZW and ZE their zenith distances by observation; from their declinations we get PW and PE their polar distances, and from the difference in their right ascensions we have the polar angle WPE. Thence, in the triangle WPE, knowing the angle WPE and the two sides PW and

PE, we can compute the side WE, which is the distance between the two stars, and also the angles PWE and PEW.

Again, in the triangle ZWE, knowing the three sides, we can find the angles ZWE and ZEW. Then the difference or sum of the angles PWE and ZWE, or of PEW and ZEW (always using the star farthest from the meridian), will give PWZ or PEZ, the difference or sum being taken according to the position of the stars with reference to the pole and the zenith.

Lastly, in the triangle PWZ, knowing the two sides, PW and ZW, and the included angle PWZ, or in the triangle PEZ, knowing the two sides PE and ZE, and the angle PEZ, we can find the remaining side, PZ, the co-latitude.

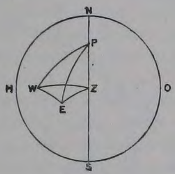

Fig. 5.

Stars which at their meridian passage are very near the zenith, or which pass the meridian the one north and the other south of the zenith, are not suitable for this observation. The computation of the latitude from simultaneous altitudes is very much shortened by using the late Admiral Shadwell's star tables, but when these are not available, Raper's general solution of the "double altitude" problem will be found a convenient method.

There are many other observations from which the latitude may be obtained, but those of which I have spoken are quite sufficient to enable the explorer to fix the position of his starting point in latitude, and I will, therefore, proceed to describe some of the most convenient methods for finding his longitude by astronomical observations.

If an explorer is provided with a good half-chronometer watch, the error of which on Greenwich, or some other place of which the longitude is known (such, for instance, as Zanzibar or the Cape Observatory), he can, with very little difficulty, find his longitude by taking sets of altitudes of heavenly bodies when they are about four hours east and west of the meridian, noting the time by the watch of each altitude, and computing therefrom the local time at which the altitudes were taken. The difference between the time thus found and the time shown by the watch, corrected for its original error on Greenwich and its daily rate, will be the longitude in time east if the Greenwich time is less than the local time, west if it is the greater. By referring to *Fig.* 6, which is a projection of the celestial sphere on the plane of the observer's meridian, we see what data we obtain from this observation for computing apparent time at place, and also the true bearing of the heavenly body.

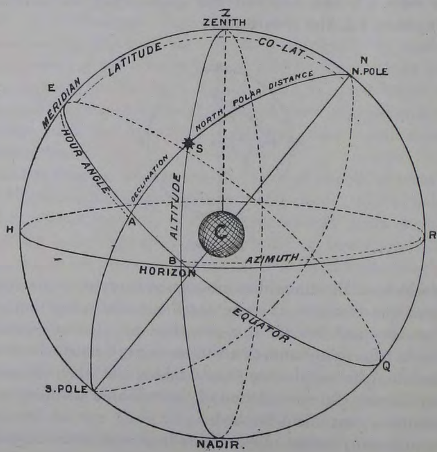

Fig. 6.

Let S be the heavenly body, then BS will be its altitude, which, subtracted from 90°, will give SZ, its zenith distance. AS is the declination taken from the *Nautical Almanac*, and this, subtracted from 90°, gives SN, the polar distance. Again, RCN, the elevation of the pole above the horizon, is equal to the latitude of the observer, and this, subtracted from 90°, gives NCZ, the co-latitude. Thus in the spherical triangle ZSN we have the three sides NS, NZ, and SZ to compute the angle ZNS, which is the hour angle or apparent time at place, and also the angle NZS, the azimuth of the heavenly body.

Stars, east and west, are the most suitable objects for time observations when about four hours from the meridian, as the results will be less affected by any error in latitude than when the hour angle is smaller, besides which, the fact that a star changes its altitude rapidly in that position enables more accurate observation to be taken. We can also generally select a pair not differing much in altitude, and, therefore, equally affected by refraction. These observations can be completed within a short space of time, which is not the case with the sun, as about eight hours would, in most cases, have to elapse from the time of the A.M. observation before the P.M. observation should be taken, and in the interval considerable changes may have taken place in the atmosphere, greatly altering the effects of refraction. Indeed, it may generally be stated that stars should always be chosen by the explorer for observing in preference to the sun.

When the common form of artificial horizon is used, the glass roof should be changed end for end between each set of observations, and the index error of the sextant should always be taken. With the transit theodolite, the altitudes should be taken in pairs, with the vertical circle first to the left and then to the right, as this eliminates errors.

As regards the independent methods of determining longitude, I shall have something to say in my next lecture, but I now propose to show how an explorer, having fixed the position of his starting point by such observations as I have already described, may proceed to map the country. In order to do this by the method I am about to explain, he should first prepare a Mercator's projection that will include the area he intends to map. The reason for making choice of Mercator's projection is that it is the only one on which a line of bearing will intersect every parallel and meridian at the same angle, thereby enabling all relative bearings to be readily and correctly laid down by straight lines. Now, supposing an explorer was camped at the spot indicated on *Plate*, *Fig.* 1, he would at once see that from the summit of the hill A he could command an extensive view of the country through which he was about to travel, and his first business should, therefore, be to fix its position as accurately as possible, and lay it down on his Mercator's projection. Having done this, he should, from the summit of A, look for some prominent and distant object in the line of march, such as the hill B on the figure, and then find its true bearing by measuring its angular distance from the sun. If a sextant is used, all such measurements must be reduced to the horizon, but with a theodolite it will only be necessary to make the hill B his zero point, and then observe the altitudes of the sun with the vertical circle, face right and face left, in pairs, noting the times, altitudes, and the horizontal angles. With the time and altitudes he must then compute the sun's true azimuth, and by applying the mean of the horizontal readings to this he will, of course, obtain the true bearing of B. The next step will be to set off indefinitely, on the Mercator's projection, this line of bearing from A, and the point B will be somewhere on that line. Having thus obtained the true bearing of B, the true bearing of any object in sight can, of course, be at once known by making B zero, and measuring the angular distance between it and B, or, if furnished with a plane table, regarding B as the other end of a base, and drawing rays to each object, marking each ray in such a manner as to prevent any future mistakes as to the object through which the ray is drawn. We will now suppose the explorer to have started on his journey in the direction indicated by the line AB, meeting with the obstacles which make it impossible for him to travel in a direct line towards B, that he allows his watch to run down, thus losing his Greenwich time, or the time of such other place as he has chosen for his reference meridian, and that, after several days' march, he finds himself in the vicinity of B. There he will have an opportunity of fixing the position of B, finding the error of his watch on his reference meridian, and by using this station as an end of his base, and drawing rays through the points from which rays were drawn at A on his plane table, and so making a sketch map of the country through which he has passed. In order to do this, he must ascend B, and take a series of observations for latitude by north and south stars. The mean of results so obtained ought to be very near the truth. For the sake of illustration, let us suppose that the latitude was 5° N., then, by placing a straight-edge on that latitude on each side on the graduated meridians, and drawing a line between those two points, its intersection with the line of true bearing of B drawn from A will be the place of B on the map. Again, placing the straight-edge on the point of intersection of this parallel of latitude and the line of true bearing of B from A, and then moving it until it is parallel with the graduated meridian, it will cut the graduated parallel in the longitude of B, which in this case would be 30° E.

Having thus found the latitude and longitude of B, the next thing to be done is to find the error of the watch, which we will suppose to have been set approximately by sunset, or the sun's meridian passage, to local time. This should be done by observing stars east and west of the meridian, and taking the mean of results as the error of the watch at the time and place of observation. Then, as we know the longitude of the station, we can at once tell the error of the watch on Greenwich, or the meridian of the place from which the longitude has been reckoned. Thus, supposing we found the watch to be fifty minutes fast of local time, then, as the longitude of B is 30° E., local time would be two hours ahead of the reference meridian, and the watch would, therefore, be two hours and fifty minutes fast of that place.

The principal drawback to this system of surveying is that it cannot be put in practice when the direction of the line of route approaches east or west, as the angle between the parallel of latitude and the line of bearing would then be too acute to give satisfactory results. In any other case, however, with care in observing, it is capable of great accuracy. An officer who studied with me previous to his leaving England, at my suggestion adopted this system of fixing his principal points by azimuths and latitudes in a route survey which he has just completed, and the results have been most satisfactory. In this case he was able to check the accuracy of his work on his return towards the coast by the bearing of a lighthouse which, from his elevated position, he could see at a great distance, and he found that after a journey over a rough country occupying a considerable space of time, his error on his closing point was remarkably small. It cannot, of course, be contended that this, or indeed any other system of route surveying which an explorer can employ, will give absolutely accurate results, but the case I have quoted abundantly proves that where judgment is shown in selecting points at good angles, and where the latitude is carefully observed by north and south stars, the results will be infinitely more satisfactory than, under ordinary circumstances, they could possibly be from a compass survey in which the distances along the line of march are arrived at by estimation.

The following is another method by which the explorer, if he has a good watch, can fix the position of B with reference to A, and thus establish a base for plane-tabling. Let us suppose that, through negligence or some unavoidable circumstances, a traveller allows his watch to run down, and having done so, jumps at the conclusion that he has lost his Greenwich time, his watch is of no further use to him than as an ordinary time-keeper for regulating the affairs of his camp, etc. Of course, he ought to know better; but, judging from the remarks I have heard, he frequently does not. It is quite true that under these circumstances, with the aid of his watch he cannot fix his longitude from Greenwich, yet he can, with great facility, do so with reference to any other place at which he ascertains its error on local time and its daily rate. This place, in the present instance, would be the hill A on *Plate*, *Fig.* 1, and he should proceed as follows :—His watch having run down, he must first set it approximately to local apparent time, and the simplest way of doing this is by observing with a sextant and artificial horizon, or transit theodolite, when the sun attains its greatest altitude; this will, of course, be 12 o'clock apparent time. The watch should be set beforehand to this hour, and wound and set going as soon as the greatest altitude is taken. This may be as much as five minutes in error, but will be quite close enough for our purpose. In the tropics, this could not be done with the sextant and artificial horizon, owing to the sun's great meridianal altitude. This, of course, would not affect a transit theodolite, but in any case star observations are preferable to those of the sun, and the explorer should calculate roughly the mean time of the star's meridian passage in the following manner :—From the right ascension of the star substract the sidereal time of the preceding noon (increased, if necessary, to make the subtraction, by 24 hours), and further diminish the result by 10 seconds for every hour; the result will be the local mean time when the star will be on the meridian, or, in other words, attains its greatest altitude. The watch must be set to this time, and when the greatest altitude is observed (not before), wind it up and set it going. The next thing to be done is to find the exact error of the watch on mean time at place. There are several ways of doing this, but the methods I have referred to of finding the time by stars east and west of the meridian is as good as any. These observations should be repeated at the same station after an interval of several days, and the difference of the errors deduced from these two sets of observations, divided by the number of days elapsed between the observations, will give the daily rate of the watch. Having found the error and rate of the watch at A, we will suppose the traveller to proceed to B, where he takes a similar set of observations, and finds the error and rate of the watch at that station; the sum of these, divided by two, will be the mean rate. He has now got all the data he requires for finding the difference between A and B, and this he does in the following manner:—The time when the last set of observations was taken at the first station must be reduced by the mean rate of the watch to the same instant as when the first set of observations was taken at the last station, and the difference between the time so reduced, and the time of the first observation at the last station, will be the meridian distance or difference of longitude between the two stations. If the error of the watch at both stations was found to be slow on the local time, then (after reducing the error of the watch by the mean rate from the first station to the second), if the watch is less slow at the second station, the meridian distance will be west, because, by travelling to the west, a slow error on the local time at the first station has been reduced. On the other hand, if the error at the second station, after being reduced by the mean rate, should be more slow, then the meridian distance will be east, because, by travelling east, a slow error on the local time of the first station has been increased.

If the error of the watch at both stations is fast, then (after reducing the time of the first station to the second station by the mean rate), if the watch is less fast at the second station, the meridian distance will be east, but if it is more fast at the second station the meridian distance will be west.

When the watch at the first station has a slow error on local time and a fast error on the second station, then the meridian distance will be west, because the direction travelled must have been west to have changed a fast error on the local time at the first station to a slow one at the second station, but when the watch at the first station has a fast error on local time, and a slow error at the second station, the meridian distance will be east, because the direction travelled must have been east to change a fast error on local time at first station to a slow one at the second station. As these directions are somewhat puzzling, I have given an example, and the following considerations may, perhaps, help the explorer to decide whether his meridian distance is east or west. If a watch is one hour slow of local mean time, it is showing correct local time of a place 15° W. of that place, and if it is one hour fast of local mean time it will show the correct local time of a place 15° E. of that place. Bearing this in mind, there should be but little difficulty with regard to naming the meridian distance east or west.

Example.

8.40 a.m., Sept. 4th.

	h.	m.	secs.	
At Blantyre, Watch...	0	0	40	fast of local time.
3.50 p.m., Sept. 9th.				
At Blantyre, Watch...	0	0	6	,, ,,
Difference =	0	0	34	

```
          days      secs.
Interval  5·3)34·000(6·41 daily rate losing.
              31·8
              ----
               2·20
               2·12
               ----
                ·80
                ·53
```

4 p.m., Sept. 18th.

	h.	m.	secs.	
At Nikula, Watch	0	11	28	slow of local time.
3.45 p.m., Sept. 22nd.				
At Nikula, Watch	0	11	56	,, ,,
Difference =	0	0	28	

```
                      d.  s.
          Interval    4)28
Daily rate losing          7
Former rate       =     6·41
                      2)13·41
Mean daily rate   =     6·70
```

	h.	m.	secs.	
Error of watch at Blantyre at 3·50 p.m. Sept. 9th .	0	0	6	fast.
Nine days' mean rate	0	1	0·3	*losing.*
Error of watch at Blantyre at 4 p.m. Sept. 18th... ...	0	0	54·3	slow.
Error of watch at Nikula at 4 p.m. Sept. 18th	0	11	28	slow.
Meridian distance, or difference of longitude between Blantyre and Nikula	0	10	33·7	

The meridian distance in this case is *east*, because the watch is *more slow* at Nikula than at Blantyre.

	deg.	m.	secs.	
Longitude of Blantyre	35	3	54	E.
Meridian distance *east*	2	38	25·5	E.
Longitude at Nikula	37	42	19·5	E.

By either of the two systems that I have last mentioned, the positions in longitude of all stations, relatively one to the other, can be fixed with considerable accuracy, and it must be remembered that if at a future time the position of any of these places as regards Greenwich is correctly determined by astronomical observations, it will also correctly fix all the other positions which have been laid down in the survey by either of these methods.

It will not, I think, be out of place to conclude this lecture with some remarks on the instruments which I have mentioned as being suitable for use in explorations, viz., the sextant, artificial horizon, transit theodolite, and watches.

With regard to the comparative merit of the sextant and transit theodolite, I may at once say that each of these instruments has much to recommend it to the explorer. The sextant has the advantage of being a much lighter and more portable instrument, and as far as observations for time and latitude are concerned, is, in my opinion, superior to the transit theodolite; but for measuring horizontal angles it is inferior to that instrument, as its use for this purpose entails the necessity of reducing all such measurements to the horizontal plane. The sextant is also a more difficult instrument to use, as the observer is his own stand, and when the inverting telescope is used, his slightest motion is magnified about eight times, which, to the novice, makes star observing with the artificial horizon a somewhat difficult business. In this, however, as in all other matters, practice makes perfect, and the intending explorer should not be discouraged because he finds it difficult at first to bring the star reflected by the sextant mirrors, and that in the artificial horizon, into contact. The first thing to remember in this class of observation is that the star, having been brought down with the sextant, and the index clamped to the altitude, can always, by vibrating the sextant, be brought into the field of view when looking at the artificial horizon. The next thing to do is to place the head so that the star reflected in the artificial horizon can be seen while the observer is in a comfortable position, at the same time holding the sextant slightly out of the plane joining the real star and its reflection in the artificial horizon. By this means the observer is sure that the star he sees is the one in the artificial horizon, and he can then, by vibrating the sextant round the axis of the telescope, at once bring the star reflected by the sextant mirrors into the field of view. With a counterpoise stand, all the difficulty of unsteadiness is removed, and an eight-inch sextant for taking altitudes for all practical purposes is equal to any theodolite. The counterpoise stand adds about ten pounds to the sextant, and the saving of this weight is, in many cases, of importance to the traveller, but even then it would be quite twenty-eight pounds lighter than a six-inch transit theodolite and stand, besides being much more compactly packed, and thus more convenient to carry.

There are many forms of artificial horizons, the lightest of which is the "black plate." Unless, however, the surfaces of the glass are exactly parallel, and the instrument accurately levelled, good results cannot be obtained. It has also the defect of giving such faint images of stars as to greatly increase the difficulty of observation, and for this reason it cannot be recommended. George's artificial horizon is a convenient form, and carries its own supply of quicksilver in an attached reservoir. A glass disc is floated on the quicksilver to steady it; but this is insufficient in windy weather, and as the glass cover that screws on introduces distortion, it should not be used, though it is intended by the maker to meet that difficulty. For the explorer, the old form of roofed horizon is doubtless the best, but the roof should never be used unless there is sufficient wind to render it necessary. These horizons are now made with folding roofs, and, when constructed in this manner, occupy a much smaller space than when the roof is a fixture. Cheap sextants and cheap artificial horizons should be avoided, and the sextants, as well as the glass used in the artificial horizon, should not be bought without a Kew certificate.

As I have no doubt that you are all well acquainted with the adjustment of the transit theodolite, I will only say that, for such observations as an explorer is likely to take, it should have three vertical and one horizontal cross hairs in the diaphragm, that all observations should be taken with the vertical circle face left and face right, and that it should be very firmly set up. For measuring horizontal angles it is far superior to the sextant, and it can be used for obtaining the longitude by moon culminating stars, which the sextant cannot.

In speaking of time-keepers, I have used the expression half-chronometer watch; this term is usually applied to a fusee watch that has been thoroughly compensated for temperature and adjusted in all positions. These watches are not so frequently made now as formerly, owing to a class of watch known as the "Going Barrel" being more easily manufactured, but these are not so suitable for astronomical work for the following reasons:—

A "Going Barrel" watch derives its motive power directly from the running down of the mainspring, and, therefore, is difficult to adjust for a regular rate for every hour of the day; there is generally a variation in the rate during the twenty-four hours, as the mainspring exerts more power when fully wound than when nearly run down, but this loss of power can be, to some extent, compensated for by having a very long mainspring.

A fusee watch has a chain which is on a spiral arbor, and is so constructed that as the mainspring loses power it gains a corresponding increase of leverage. This arrangement converts the varying force of the mainspring into a constant pressure at the centre pinion, and thus admits of the watch having a regular rate for every hour of the day. Makers will probably tell you that the best rates taken at Kew have been those of "Going Barrel" watches; this is quite true, but then, as I am informed, the rates are taken at that establishment at or about the same hour every day, and afford no test as to the regularity of the rate at other times. I have carried out these tests with a "Going Barrel" watch which at a fixed hour had a capital rate, but at other times varied its error considerably.

At the Royal Geographical Society we never supply travellers with chronometers, experience having taught that they are not so well suited to the traveller as the half-chronometer watch. Such as we do supply are placed in a case of my own invention called the "Coles' Water-tight Case." These have no hinges or springs, and are perfectly dust and water-tight. They are made by H. Blockley, of Duke Street, Piccadilly.

In my next lecture I propose, after mentioning some other methods of surveying suitable for explorers, to deal with observations for finding the longitude by occultations, moon culminating stars, Jupiter's satellites, and lunars, and to conclude with some remarks on photography as an aid to the explorer.

LECTURE II.

In continuation of my last lecture, I will call your attention to a system of route surveying which has been very successfully carried out by Mr. Holt Hallett and Mr. Skipton in their preliminary railway surveys in Siam. In both cases these gentlemen travelled on elephants, and that will in some measure account for the remarkable accuracy with which the distances were estimated through a rough and mountainous country, the discrepancies in their maps being much less than would have been expected.

If the system I am about to explain could only be carried out when the explorer was mounted on an elephant, I should not have brought it before you; but this is not the case. It can be equally well used by a person on foot, except, of course, that the view from the back of an elephant would be more extensive, and there are also the advantages of being able to place the instruments in the howdah in a convenient position for use, as well as the much greater regularity in the elephant's rate of progress.

I should, perhaps, preface what I am going to say by a brief description of the country through which this route survey was carried. It was so thickly covered with jungle that it was often difficult to obtain a view 50 yards ahead. The track frequently followed the tortuous beds of mountain streams, rising, in some instances, nearly 1,000 feet above the plain, the descent being made in a similar manner, and in this way numerous ridges were crossed. It will thus be seen that it was about as difficult country as can well be conceived, and that to survey it with the prismatic compass and chain would have been an exceedingly slow operation, while hastily-taken chain measurements by natives over a track such as I have described would, in all probability, have been much in error.

The only instruments used in this class of survey are a watch, aneroid, and a compass. It has been found that an ordinary compass, mounted on gimbals, is better for use on an elephant than the prismatic compass; but the explorer on foot would, of course, use the latter. The note-book should have horizontal lines, and three vertical columns, as shown in the following table, which is taken at random from a note-book of a survey from Chieng-Mai to Muang-Prey:—

Table.

Remarks.	Time.	Bearing.	Minutes of Bearing.	Remarks.
	h. m. 10	degrees. 130		Plenty of water.
	5	120	5	Very little water flowing.
	3 00	100	5	Following down brook. Bar. 29·83, Ther. 96°
	2 56	110	4	
	2 46	70	10	Brook with puddles. Pang very large.
Off to the right a road goes to M. Prey	2 40	80	6	
Summit; Bar. 29·71, Ther. 97°	2 20	90	20	
				This lies 90° from summit; appears ahead.
	2 14	120	6	Great stone face of rock.
Granite...	2 11	110	3	First telegraph post. River flows away to right, and country level.
Ascend tail of east spur	2 3	90	8	Eastern spur dies out. Bar. 29·77, Ther. 97°.
	1 53	150	10	Sala Pa Kaw.
	1 45	240	8	Plenty of water in river.
	1 36	160	9	
	1 30	180	6	Been in all morning.
December 13th, 1888...	1 6	170	24	Same stream we have Meh-Lan.
Halt for breakfast ...	11 55			
	45	180	10	
	35	130	10	

You will observe that the time of the change of each bearing is noted in the first column, the bearing itself in the second, the length of time travelled on each bearing in the third, and other notes in the margins. If a rough sketch of the longitudinal section is made on the page of the note-book, it will be found of great assistance in plotting the work. Bearings to well-defined hill-tops should be noted, and, if possible, a good referring mark left on the summit of each hill crossed, such as a piece of trade-cloth fastened to a long bamboo, or securely tied to the top branches of some large tree. These marks can often be "picked up" looking back, and serve as valuable checks on the bearings.

In this system there is no lineal estimate of the distance travelled on each bearing, instead of which the time occupied is noted. From this latter, when the average rate of travel on the level is known, the distance may be obtained. This can, of course, easily be done by taking the time occupied in passing over an accurately measured distance on the level at the usual pace; but this will not give the rate of travel on steep and continuous ascents or descents, for which a correction must be applied, and which can most readily be obtained by making a barometric section of a fairly steep ascent, measuring a distance on it, and then taking the time occupied in passing over it at the usual pace, both up and down; then regarding this as the hypothenuse, reduce it to the base, which will, of course, be the distance travelled on the level, and will give a very fair ratio for correcting the map plotted from the field sheet. Making these corrections is a very important point, as, if neglected, the bases of the hills will be extended beyond their proper proportions, and the valleys, of course, narrowed. The fact that uncompensated work, when plotted "fitted in," would be no proof that it was accurate, as can easily be seen by referring to *Fig.* 7.

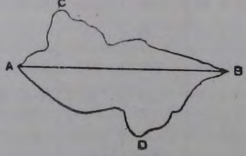

Fig. 7.

Suppose that an explorer made such a route on a map as ACB, and another ADB, and that when plotted, without any compensation for mountains crossed, they "fit in," or nearly so, so far as the points A and B, and the bearing AB, are concerned, this does not prove the work to be accurate, and it only shows that the lack of compensation is common to both.

The work should be plotted every evening, ready for reference on the following day, as the general lie of the bearings will show where to look back for checks when any favourable spot may present itself for that purpose. An easy mode of plotting the work is to draw on the paper a line from east to west, and on this prick off a protractor, then with a parallel ruler the bearings can be laid down on a Mercator's projection until the plot is inconveniently far from the protractor, when another protractor can be pricked off in the same way. These protractors on the plot will be found very useful when looking back for checks. The plot should first be made to a time scale, and a longitudinal section to the same horizontal scale, without any allowance for rise or "compensation." Then from this plot, with the aid of the back checks and ratios of corrections established, a map can be made to a lineal scale with the proportional compasses.

It may very possibly be asked why a time scale should be used instead of one of estimated distances, as the time scale must eventually be converted into a linear one, based on an estimated speed of progress, and it would at first sight appear to be expressing the same thing in different terms. This, however, is only the case to a certain extent, as judging the distance travelled would, of course, be mere guess-work, and might be more or less than the truth, while the time taken from the watch is that which is actually occupied and measured, and if the accepted mean rate of progress on the level is near the truth it will, after being compensated for rise or fall, give much more accurate results than any merely estimated distance would be at all likely to do.

To my audience this may appear, as it doubtless would be in careless hands, a very rough way of making a route survey. It must, however, be remembered that my subject is surveying suitable for explorers, and I am well within the truth when I say that a large proportion of the first knowledge we obtain of the topography of previously unexplored countries is derived from much more crude systems than that of which I have spoken. In experienced hands, this method is capable of great accuracy, as a sheet kindly lent me shows.

At a subsequent period, a survey with a theodolite and chain was made over the whole distance from Chieng-Mai to Muang-Prey, about 100 miles in the straight, and it was found at the end that there was only a difference of 1·6 miles between the preliminary and accurate surveys.

There are other methods of surveying in a mountainous country, or through a heavily-wooded region, in which the plane table or tacheometer could be used by the explorer with advantage, but within the limits of time at my disposal I am unable to describe them, and will, therefore, pass on to my next subject, viz., the methods by which an explorer may fix his longitude by independent observations, the best of these being occultations of stars by the moon.

The moon, being the nearest of all visible heavenly bodies, must in her monthly revolutions necessarily pass between many other celestial objects and the earth, and an occultation, is therefore, possible when the moon's course, as it would be seen from the earth's centre, carries her within an apparent distance from a star equal to the sum of her semi-diameter and parallax. This disappearance of a star from this cause is called an immersion, and its reappearance from behind the moon is called an emersion. The disappearance must always take place on the eastern limb of the moon, because her motion among the stars is from west to east. Before full moon the star will be occulted by the dark limb and reappear from behind the bright limb, but after full moon the opposite to this will be the case.

From the following considerations it will be seen that the occultation of a star can only be observed within certain limits of latitude. Stars are so distant that all straight lines drawn from them to any two places on the earth's surface would appear to be parallel, and thus we may consider these lines to form the limits of a cylinder whose axis is a line joining the centre of the moon and the star enveloping the moon and extending to the earth, and it follows that only those persons who are enclosed by that cylinder on the earth's surface will be able to observe the occultation ; to all of these, however, it may be visible.

The limits in latitude beyond which the occultation of a star cannot be observed are given in the *Nautical Almanac*, but it does not follow that, because the observer's latitude is included between these limiting parallels, the occultation of the star will be visible to him. For instance, the moon may not be above his horizon at the time of conjunction, and an explorer will have to take this into consideration when he determines to make a lengthened halt for the purpose of fixing the position of some place in longitude by an occultation which will take place at a future date, or when he endeavours to reach some distant point for the same purpose. Even if his position in latitude is comprised within the limiting parallels, it may be so nearly on the verge of one of them that, though visible, it can only be very partial, and will, therefore, be ill-adapted for determining longitude. In all doubtful cases the circumstances of the occultation for the date and place should be computed beforehand. To do this by Woolhouse's formula involves a larger amount of labour than most explorers would be inclined to devote to it, but the prediction can be attained with sufficient accuracy for all practical purposes by the late Admiral Shadwell's tables, or Penrose's graphic method. This is not, however, necessary in all cases, especially when the observer is centrally situated as regards the limiting parallels, and knows that the moon will be visible, in which case he can proceed as follows :—

During the day he should find the local time of the phenomenon by applying the assumed longitude in time to the Greenwich mean time of conjunction of the moon and star, which he will find among the "Elements of Occultations" in the *Nautical Almanac*, adding the longitude in time if it be east, and subtracting it if it be west. An hour before the time so found, he should point his telescope to the eastern limb of the moon ; it is necessary to take this precaution, as the assumed longitude may be considerably in error. The moon will be seen to approach the star from west to east until its eastern limb will reach the star and occult it ; note the instant of time when this takes place. After a certain interval, the star will appear on the other side of the moon ; note this time also. Either of these observations is sufficient to determine the Greenwich mean time, and thence the longitude.

Several methods have been proposed by different authors for deducing from the above occultation the time of true conjunction of the moon and star. Of these "Raper's" method, which I have given in the Royal Geographical Society's *Hints to Travellers*, is, perhaps, the most convenient for the explorer.

Figs. 8 and 9 will, I think, explain the principle on which this observation depends.

NQS′E is the observer's meridian, NGS′ is a meridian to the east of the observer near to the moon, the central circle represents the earth, on which an observer is situated at D; Z is his zenith, HR his horizon, and ZFN′ the circle of altitude on which the moon is situated, A shows the true position of the moon, which from D would appear at the position B′ in the heavens, occulting the star S. From C, the earth's centre, the moon A would appear in the heavens at B, after having occulted the star S, which latter would always appear in the same position, whether viewed from the earth's surface or its centre, as it is unaffected by parallax. If B be the position

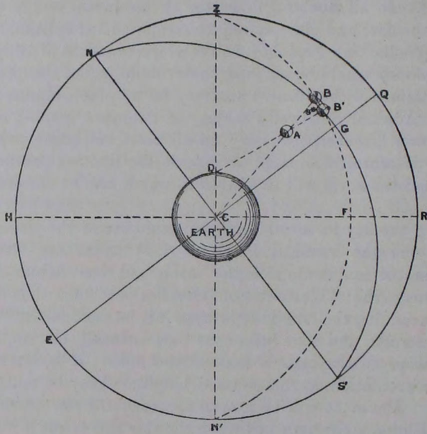

Fig. 8.

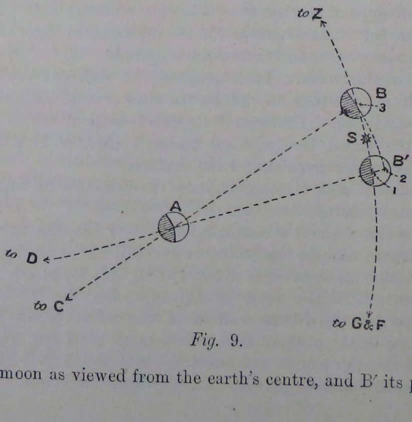

Fig. 9.

of the moon as viewed from the earth's centre, and B′ its position as seen from D at the same instant, then 2 3 is the parallax in declination, 1 2 the parallax in right ascension. With these the true time of conjunction can be computed by the method I have previously recommended.

My reasons for saying that occultations are the best of all the absolute methods which an explorer can use for determining the longitude are that the instrument employed, a telescope, is one with the use of which everyone is acquainted, and is not liable to get out of adjustment, that the observation is easy, and, when the star is occulted by the moon's dark limb, instantaneous; all the observer has to do is to be quite sure that he sees the star one instant and that he does not the next. Then, as regards the star, he can hardly be mistaken as to the one that will be occulted if he bears in mind that the moon moves among the stars about its own diameter in one hour, so that if he commenced observing, as I have recommended, an hour before the predicted time, he could, without difficulty, be sure of the star, as it would be within a distance equal to the moon's diameter from the limb by which it will be occulted. He must, however, bear in mind, when the dark limb is in the question, that the phenomenon takes place when the star is some distance from the illuminated part of the moon. I may also state that I have tested this class of observation thoroughly from stations the longitudes of which were well known, and I have always obtained very accurate results when the stars were occulted by the dark limb. When the bright limb has been employed, I have obtained good results, but not so good as with the dark limb, and I have also found that immersions give better results than emersions, for the reason that they can generally be more accurately observed.

The next method of finding the longitude to which I will call your attention is by moon culminating stars. The principle upon which longitude is found by this observation is similar to that which is employed in most absolute methods, and depends on the observed motion of the moon; but in the present case, instead of measuring the distance between the moon and a star with the sextant, as with lunars, this motion is ascertained by observing with a transit theodolite or transit instrument the time when the moon's bright limb passes the meridian, in which position its right ascension is not affected by parallax, and immediately afterwards, one or more stars. Then, as the right ascension of the star is known, and for all practical purposes does not change in a short interval of time, we can, by a simple and short computation such as I have given in the

Royal Geographical Society's *Hints to Travellers*, page 203, with the sidereal interval between the transits of the moon's bright limb and the star, find our longitude. The only time-keeper required is one that will measure the interval, frequently about ten minutes, accurately. In order to take this observation, it is necessary that the telescope should be accurately set up in the plane of the meridian. This can be done by either of the following methods :—

By Meridian Passage of the Pole Star.—Find the mean time of the meridian passage of the Pole star. Level the instrument, and if this be carefully done, the line of collimation will move in a plane perpendicular to the horizon, and will pass through the zenith, then, by making it also pass through the celestial Pole, and clamping the horizontal plates when it is in that position, the movements of the telescope will be restricted to the plane of the meridian. This is done by turning the telescope on to the Pole star, and covering it with the point of intersection of the telescope hairs, at the time (previously ascertained) of its upper or lower culmination, and then firmly clamping the horizontal plates.

By High and Low Stars.—This method is accurate, and will be found convenient when the Pole star cannot be observed. Having placed the instrument approximately in the meridian, choose two stars, differing considerably in declination, and but little in right ascension. Note carefully the time that each star passes the central hair ; take the difference of these times, to which apply the rate of the watch due for the interval, and convert this into a sidereal interval by the *Nautical Almanac* table of time equivalents. Take from the *Nautical Almanac* the apparent right ascension of the stars, and subtract the less from the greater. If this difference agrees exactly with the sidereal interval obtained by the watch, the telescope will move in the meridian ; but when this is not the case, and the interval shown by the watch is less than the difference of the star's right ascensions, the telescope must be moved to the west ; if the contrary be the case, the telescope must be moved to the east. This must be repeated until the sidereal interval, computed from the watch times of transit, and the difference of the star's right ascension, taken from the *Nautical Almanac*, agree exactly ; the telescope will then move in the plane of the meridian. Select a star as near the zenith as possible for the "high star," as when the instrument is truly level the telescope will be on the meridian when pointing to the zenith, no matter how much it may differ from the meridian when in any other position.

By Meridian Passage of any Star.—Any star may be used if the local time is accurately known, and the time of the star's meridian passage carefully computed. The observation is precisely the same as for the Pole star, but it would be well to take more than one star, in order to correct any errors that may have been made in observation or computation. Though the results of observations by the meridian passage of stars are susceptible of a great degree of precision where local time is accurately known, yet absolute accuracy must not be expected.

By Stars East and West of the Meridian with the Transit Theodolite.—If local time is not accurately known, the true meridian may be found in the following manner:—Carefully level the transit theodolite, and, for convenience, set the 360° division of the horizontal plate as nearly true north as you can get it by the attached magnetic needle, then clamp the lower plate, and unclamp the vernier plate. Select any star at some considerable distance east of the meridian, and cover it with the intersection of the hairs in the diaphragm, clamp the vertical circle, and take the reading on the horizontal plate. Then, after the necessary interval, watch the star until it is again covered with the intersection of the hairs in the diaphragm west of the meridian, take the reading, and then the theodolite will point just as far west of the meridian as it originally did to the east, and a point mid-way between these two horizontal readings, if the meteorological conditions remain the same, will be in the true meridian. Care must be taken to keep the vertical circle and the lower plate clamped during the interval between these two observations.

In addition to these methods, I have here an instrument (*Fig.* 10) which fits on the telescope of my plane table alidade, but which I also employ for these observations by fixing it on a brass plate with levelling screws which fits on to my theodolite tripod. It is called a solar compass, and by its aid the telescope can be very readily placed in the meridian. It consists, as you may see, of a small telescope and level, the telescope being mounted on standards between which it can be elevated or depressed. The standards revolve round an axis, which is fastened to the axis of the larger telescope. Two pointers are attached to the small telescope to be used in approximately setting the instrument, and are so adjusted that when the shadow of the one is thrown on the other, the sun will appear in the field of view.

To use the solar compass, after having carefully levelled the instrument, take the declination of the sun, as given in the *Nautical Almanac*, for the given day and hour, and correct it for refraction. Incline the larger telescope until this amount is shown on the vertical arc. If the declination of the sun is north, depress it; if south, elevate it. In south latitude this is reversed. Then, without disturbing the position of the larger telescope, bring the solar telescope horizontal by means of its level. The two telescopes now form an angle which equals the amount of the declination. Without

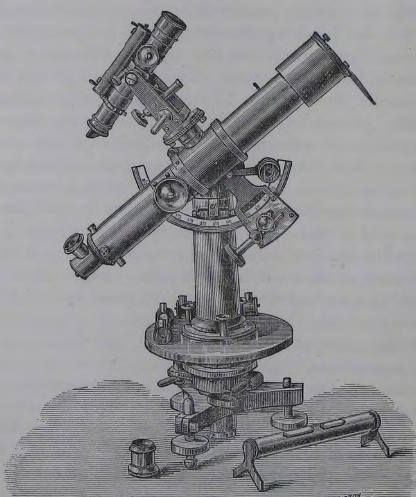

Fig. 10.

disturbing the relative positions of the telescopes, set the vernier of the vertical arc to the complement of the latitude of the place. By moving the larger and solar telescopes around their vertical axes, the image of the sun will be brought into the field of view of the solar telescope, and after actually bisecting it with the solar telescope, the larger telescope must be in the meridian, as the solar telescope is, in fact, a small equatorial.

If the instrument is to be used with stars at night, all that is necessary, to test the accuracy of the adjustment, is to get some well-known star in the field of the solar telescope, keeping the larger telescope clamped in azimuth, and see if, after an interval, it still continues in the centre of the field; if it does, the larger telescope must be in the meridian.

Until very recently there were, as far as I know, only two of these instruments in this country, though they have been for some time extensively used in the United States. One of these is in possession of Mr. Alfred Maudslay, who studied with me, and was used by him with great success in surveying and finding the longitude by moon culminating stars in Guatemala. The other is the one before you, which I have frequently used for the same purpose during the past three years. I got both these instruments made by Cary, 181, Strand, after a pattern kindly lent me by my friend Mr. Josiah Pierce, of the United States Coast Survey, with certain modifications which I have introduced to make it available for star observing. I have also placed in the focus of the larger telescope a reticulated disc of glass, the lines on which measure a constant angle of value, and afford the means, within the limits at which the graduations on an ordinary levelling staff can be read with the telescope, of measuring distances at sight with considerable accuracy; indeed, after many trials, I have found distances measured by it to be quite as accurate as chain measurements. This method of measuring distances would only be of general service to an explorer when his work was plotted on a larger scale than four inches to the mile, as its most distant range is a quarter of a mile, but it would save a considerable amount of time and work, if used in connection with the plane table, for making plans of the interior of ruins, forts, etc. The telescope of the solar attachment is so small, being only three inches in length, that it would appear unfitted for the work it is intended to do. It has, however, been used in the United States for half a century for running meridian lines in places where the magnetic needle was so affected by local attraction as to be useless, and has given a precision in results far exceeding those obtained from the compasses in places not so affected. I may also add that, having set this instrument on the meridian by the sun, I have left it in my observatory until the stars were visible in the evening, and then, without disturbing the previous meridian adjustment, I have put a star on the intersection of the hairs in the solar telescope, and have found that, after an interval of three hours, the star still remained in close proximity to the intersection of the hairs, thus showing that the instrument was accurately placed in the meridian.

Next to the occultations of stars by the moon, I consider that moon culminating stars afford the best of the independent methods by which an explorer can find his longitude, and in confirmation of this I would point to the excellent results which Mr. W. Ogilvie obtained in the Mackenzie and Yukon region, in British North America, for which he was last year awarded the "Murchison Grant" by the Council of the Royal Geographical Society. French explorers have also used this method with considerable success, and as the computation is easily understood and very short, it is to be hoped it may be more frequently used by English explorers in the future than it has been in the past.

We next come to finding the longitude by the eclipses of Jupiter's satellites. The observation is taken with a telescope, and is a very easy one, and would, therefore, seem well suited to explorers, especially as the Greenwich time is found at once without any calculation whatever, as the Greenwich time of the eclipse is given in the *Nautical Almanac.* I have found, however, by frequent trial, that the result obtained from a single observation is seldom satisfactory, but when the immersion and emersion of the same satellite are observed on the same evening, the mean of the two results will be nearer the truth. As a rule, the first satellite is to be preferred, as its motion is more rapid than the other three, but though this method is so simple, it is not very accurate, as the eclipse is not instantaneous, and the clearness of the atmosphere, and power of the telescope, affect considerably the time of the phenomenon; so much so, that observers have been found to differ 40 or 50 seconds in the same eclipse.

Another well-known method of finding the longitude is by lunar distances, which, before chronometers were brought to their present state of perfection, was frequently used by sailors, but at the present time, except some accident should happen to the chronometers, they are never used at sea. This is not the case, however, with the explorer who is provided with a sextant, but has no chronometer or reliable watch with him, and, therefore, must find his longitude independently. A general idea of what has to be done in clearing a lunar distance can be gathered from *Fig.* 11.

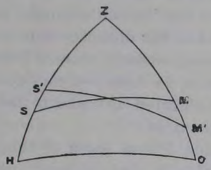

Fig. 11.

Z is the zenith of the observer, HO the horizon, M′ the apparent place of the moon, S′ the apparent place of the sun, star, or planet. Now refraction and parallax always produce opposite effects on the altitude of a celestial body, and their difference will, therefore, be the correction in altitude. As regards the moon, parallax is always greater than refraction, and, therefore, the true place of the moon M is always above its apparent place M′. With other celestial bodies the contrary is the case, and their true places are always below their apparent places; therefore MM′ is equal to the difference between the true and apparent places of the moon, and SS′ to the difference between the true and apparent places of the other object. Then S′M′ will be the apparent distance, and SM the true or geocentric distance. Now in the triangle M′ZS′, the sides M′S′, M′Z, S′Z being known, we can compute the angle Z. From the apparent altitudes HS′ and OM′ we obtain the true altitude OM and HS; then, in the triangle MZS, knowing the sides SZ and MZ (the zenith distances of M and S) and the angle Z, we have two sides and the included angle to find the other side SM, which is the true distance.

There are about 30 different methods of clearing the lunar distance, but I prefer Raper's "Rigorous" method to any, and have, therefore, given it in the Royal Geographical Society's *Hints to Travellers.*

The opportunities for observing lunar distances are of frequent occurrence. The *Nautical Almanac* gives the predicted angular distances of the moon from the sun, planets, and certain bright stars for every three hours of Greenwich time, and if the explorer accurately measures these distances with his sextant, and has previously found the error of his watch on local time by observation, he has the means of determining the Greenwich time when any of the distances were observed. I have not mentioned that he ought to observe the altitude of each celestial body, as the theory is, for the very good reason that he can compute these altitudes at the mean of the times when the distances were measured with greater accuracy than he would observe them. Neither does this much increase his computation, as there is a considerable amount of work entailed in reducing observed altitudes to the mean of times when the distances were measured.

From the description I have given of this observation, it would seem to be very simple, but a trial, under certain circumstances, will soon prove that it is not, in addition to which it is open to the following objections:—The moon making her monthly circuit in the heavens may be considered as the traveller's standard clock, but the operation of determining the exact Greenwich time by it is very much the same as it would be from a clock that had only an hour hand. Again, the moon only moves among the stars her own diameter in an hour, and, therefore, the observer must determine the position of the moon within the 120th of her diameter to arrive even within half a minute of the true Greenwich time, and when he succeeds in doing this his longitude would still be seven and a-half miles in error. The observation is also a difficult one, and has often to be taken in a constrained position, and it must be exact to give anything like favourable results, as an error of one minute in distance produces 25 minutes in longitude, or the effect of 15 seconds error of distance will produce six minutes of longitude, and this, be it remembered, under the most favourable circumstances. From this we may see that a single set of lunar distances, even when taken by an experienced observer, is of comparatively little value. But if several sets be taken east and west of the moon, the errors produced on one side have a contrary effect to those taken on the other, and thus, in the mean results, they neutralize one another. As an instance of this, I may mention that Consul O'Neill fixed the longitude of Blantyre, to be used as a secondary meridian, by several hundred sets of lunars, for which he received the gold medal of the Royal Geographical Society. Few travellers, however, possess Mr. O'Neill's skill, and fewer still, I fancy, can be found who are prepared, night after night, to spend the time when others are asleep in measuring lunar distances. All that I can say in their favour is this, that the opportunities for observing them are of more frequent occurrence than for occultations, moon culminating stars, or the eclipses of Jupiter's satellites. But they require far more skill to take, and, as a whole, can hardly be said to give satisfactory results, unless taken in sufficient numbers by a practised hand who thoroughly understands how to balance his observations.

In the remarks I have just made, I have, of course, been speaking of sextant observations, as lunar distances, unless the photographic camera is used, can only be measured by a reflecting instrument, which enables the observer to see the moon and the other celestial object at the same instant. A series of experiments are, however, being made at the present time by Dr. H. Schlichter, which, if successful, will go far to remove the difficulties and uncertainties attendant on this class of observation. This gentleman is, in fact, endeavouring, and I trust successfully, to bring in photography as an aid to the explorer, by measuring the lunar distances with a photographic camera specially constructed for the purpose. It is known that it is possible to obtain photographs of the moon, planets, and fixed stars of the first and second magnitudes on one plate with exposures of less than one minute. The photographic images of the stars appear on the plates as straight lines, in the manner shown on *Fig.* 12, which is a copy of two photographs

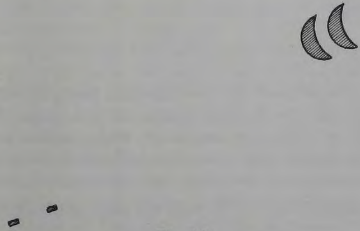

Fig. 12.

of the moon and Jupiter west of the moon, taken with an exposure of 30 seconds, and an interval between the observations of one minute four seconds. The method by which Dr. Schlichter hopes to facilitate taking lunars by the aid of photography is by measuring, with a micrometer, the distance between either end of the lines which represent the star and the moon on the plates, and he has already so far succeeded that he can measure the change of place of the moon among the stars in an interval of two minutes of time. This would, roughly speaking, be about one minute of arc. From what I have previously said it is, however, clear that the distance must be measured with much greater accuracy than this to be of any practical value. Of this fact Dr. Schlichter is well aware, and informs me his experiments have shown that if a medium sized aplanatic lens be employed an accuracy about equal to that of a sextant reading to 10 seconds can be attained, but that he hopes before long to get even better results.

The manner in which the angular distance between the moon and the other celestial bodies is measured by this method is shown on *Fig.* 13, which exhibits a side view of the apparatus.

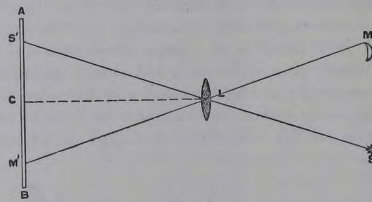

Fig. 13.

L is the lens, and AB the photographic plate, M is the moon, S the star, and M′ and S′ their images on the plate. Now as the distance LM′ can always be ascertained with absolute accuracy, and as CM′ is also known, being equal to half the distance on the plate between the images of the moon and the star, it follows that the sine of the angle $CLM' = \frac{CM'}{LM'}$, and the angle $MLS = 2CLM'$.

If this succeeds, as there seems every reason to believe it will, it will have the following advantages:—Increased accuracy of results, extreme simplicity of apparatus, and ease and rapidity with which the observations can be taken; in addition to which the apparatus can be so constructed that it will be able to stand the wear and tear of a rough journey, and if the plates are preserved, the results can be checked and re-measured as often as required. With all these prospective advantages before us, I am sure that everyone interested in exploration will wish Dr. Schlichter the success which his efforts to increase the accuracy of the determination of longitude in unexplored countries so richly deserves.

I will now proceed to consider the subject of photography as an aid to the explorer in producing his map, and with the danger of prophesying before my eyes, I will venture to say that it will soon occupy as important a place in surveying as it does in almost all other scientific pursuits. Indeed, on many parts of the Continent numberless experiments are being made in this direction, but so far as I have seen, the instruments employed are too complicated for an ordinary explorer, being nothing more nor less than photographic theodolites.

A mountainous country is the one in which the explorer can with the best advantage use the photographic camera as a surveying instrument, though on plains on which there are prominent objects it can be used with advantage. It is especially useful where the surveyor has to trust to topographical sketching of mountain ranges from distant points of observation, and I am informed that the great difficulty experienced in the Himalayas, where this class of surveying has been going on for the past ten years, and where large tracts are closed to the surveyor, lies in the fact that the same point cannot often be identified from different stations of observation, the consequence being that the greater proportion of angles measured are lost to the computor.

To obviate this difficulty, Colonel Tanner, who is an accomplished surveyor, proposes to use a half-plate camera with a rectilinear lens. This will record the true shape of every peak embraced in the view. and by applying a suitable transparent scale to the negative, the angles or azimuths, as shown by actual experiment, may be read off from the scale to within about 2′ by using a magnifying power, The ordinary half-plate with a rectilinear lens embraces about 42°, and gives a degree equal to 0·1544 inches. Besides its application to topography, Colonel Tanner informs me he has found that by a simple contrivance, celestial objects, *i.e.*, the sun, moon, brighter planets, and fixed stars of the first magnitude, can be obtained on the same plate, which enables the azimuths of objects to be secured by photographs; but to carry out the system satisfactorily, it will be necessary to introduce some slight modifications, to enable the camera to be accurately levelled.

I will now endeavour to show how an explorer with an ordinary photographic camera can materially assist in correcting and filling up a map which has only been partially surveyed. In order to do this it is necessary that five points should be accurately laid down on the map he is going to correct or add to, viz., three prominent objects, such as mountain peaks, and the places from which two distinct photographs of the country are taken. In making choice of these latter, the explorer must be careful to choose them so distant from one another that lines drawn from one of them through points in the field of view will intersect lines drawn from the other through the same points at good angles.

The first thing to be done is to select three points on the map which have been previously fixed, and from each of the stations where the photographs were taken draw lines on the map through these points. Make from the photographs tracings of all the most prominent features, and those points the positions of which it is intended to correct or add to the map. On each of these two tracings draw a horizontal line in such a way that it will occupy a position midway, or nearly so, between reference points and points it is desired to fix, and erect or let fall perpendiculars from the several points to this horizontal line. The object of doing this is to reduce the unequal heights in the photograph to a common horizontal standard.

The following operation must then be carried out with each of the tracings:—Place the tracing on the map, and move it about until the three points where the horizontal line is intersected by the perpendiculars erected or let fall from the three prominent objects chosen as our referring points are exactly over the lines drawn on the map to those points. Having succeeded in this, any object on the tracing can be transferred to the map by drawing a line from the point on the map where the photograph was taken, through the point on the tracing, and producing it as far as necessary on the map. Having done this through all the places on the first tracing, the same operation must be gone through with the second, using the place on the map where it was taken as the centre from which to draw the lines, and the points of intersection of the two sets of lines will be the positions on the map of the places on the tracing through which the lines were drawn.

This method is much more easy in practice than it is to describe, and has been very fairly tested in the map room of the Royal Geographical Society. On one occasion in particular, a series of excellent photographs was used to a great extent in filling in a map of the Adai Khokh group, in the central Caucasus, and when this country was afterwards surveyed by Russian officers, the details of our map, constructed by this method, were fairly correct. It is, of course, understood that the three points we worked from, and the places where the photographs were taken, were known, and correctly placed on the map, and it is only fair to add that in our Secretary, Mr. Douglas Freshfield, we had a gentleman who is thoroughly acquainted with the country, and could, from personal knowledge correct any great mistake. By referring to *Plate, Fig.* 2, these remarks will, I hope, be more clearly understood.

In concluding these lectures, I would express a hope that what I have said may have interested some of you. The subjects I have had to deal with are large ones, and with the time at my command I have only been able to bring before your notice some of the methods of surveying and astronomical observations best suited to the explorer. I feel sure, however, that the subject of exploration must hold an important place in the minds of officers who belong to the Royal Engineers, a Corps which has furnished to the world so many distinguished explorers, and I doubt not there are some among you who would only be too glad to have any opportunity of following their example. To such I would say that, should they become explorers, they will often find themselves in positions where it would be impossible to put in practice the refinements of a properly-conducted trigonometrical survey, and it is then that such methods as I have called your attention to will have to be used. It is on such occasions that the really good surveyor comes to the front, the man who, when surrounded by difficulties, overcomes them, and knows best how to employ the small means at his disposal, so as to make a fairly accurate map of the country through which he has travelled, and thus contribute to geographical science.

If I have failed to express myself clearly on any subject, I shall be glad to give all the information in my power to any officer who will favour me with a call at 1, Savile Row, London, and I shall have the more pleasure in doing so, as by that means I shall be carrying out the wishes of the Council of the Royal Geographical Society.

PAPER II.

THE GERMAN ARMY.

By Captain J. M. Grierson, R.A.

LECTURE I.

Organization.

I propose to divide the subject into two lectures, dealing in the first with the peace and war organization of the troops, recruiting, and the supply of officers, and in the second with the tactics and course of training of the German army. As far as possible, I shall strive to avoid wearying you with details, and to set before you the general principles and outlines of organization only.

The German army is not an entirely homogeneous force, but is made up of the contingents of the various States comprising the Empire, and these are in a manner independent in their administration, though in all the organization, equipment, recruiting, and system of tactics are identical. Under the Prussian War Ministry absolutely are, besides the Prussian army, the contingents of all the smaller German States and Alsace-Lorraine. Among these, the troops of Baden form an army corps, those of Hesse Darmstadt a division, and those of Mecklenburg two brigades by themselves, and in the two latter the officers swear allegiance to their own sovereign as well as to the Emperor, but otherwise those troops are treated exactly as Prussian troops. Bavaria, Saxony, and Württemberg maintain separate War Ministries, and the administration of the first of these armies is completely independent, subject only to the condition of conforming to Prussian regulations. The Saxon and Württemberg armies share all educational and manufacturing establishments with the Prussian army, but their officers are appointed by their own kings. While, however, Württemberg officers are interchangeable with Prussian, and frequent transfers take place, those of Saxony are not so transferable.

The recruiting law is identical for all countries in the Empire. Every German is liable to military service from the end of the 17th to the end of the 45th year of his age, and this period is sub-divided into those of active military service and of Landsturm service. Active military service is sub-divided into service in the standing army and its reserve, and service in the 1st and 2nd categories of the Landwehr. Liability to service in the standing army and its reserve begins on the 1st of January of the year in which the man completes his twentieth year, and lasts for seven years, counting from the actual date upon which the man joins his regiment, which is usually in the following November. The first three years are passed with the colours, and the remainder in the reserve ; but in many cases, so as to make room for volunteers serving to become officers or non-commissioned officers, or to keep the units within the peace establishment, men are allowed to go to the reserve after two years' service only. On mobilization, the recruits fill up the ranks of the standing army, and during their service in the reserve they are liable to two trainings of eight weeks each. Service in the 1st Ban of the Landwehr lasts for five years from date of transfer from the reserve, and during that time the men may be called out twice for fourteen days' training. On mobilization, the men of this Ban would form the so-called "reserve troops," the organization and use of which will be explained later on. Service in the 2nd Ban of the Landwehr lasts from the date of completion of 1st Ban service till the 31st March of the year in which the man completes his 35th year, *i.e.*, for about seven years, during which time the men are not liable to be called out for training. These men form, in war, "Landwehr troops." Twice a year the men of the reserve and 1st Ban of the Landwehr are mustered by the Landwehr district authorities. To the Landsturm or *levée en masse* for home defence, belong all men not borne on any of the lists of the above categories from the end of their 17th to that of their 45th year. Its men are liable neither to training nor to muster parades. It is found impossible to train, according to the above programme, all the able-bodied youth of the country for financial reasons, and accordingly lots are drawn to determine which men are to form the contingent. A certain number of those who then remain supernumerary, together with certain men excused active service for family reasons or for minor bodily defects, are chosen and passed direct into what is called the Ersatz Reserve, in which they serve for 12 years from the 1st October of the year in which their liability to active service began, after which they pass into the 2nd Ban of the Landwehr. They are liable to three trainings, the 1st of ten, the 2nd of six, and the 3rd of four weeks, but the number of Ersatz reservists so trained is fixed annually by the budget, and not nearly all can be so exercised. On mobilization, these men would fill up the depôts and furnish drafts for the troops in the field. It now remains only to mention the categories of so-called volunteers. One-year volunteers are men of good education, who, on passing an examination, are permitted to serve only one year with the colours, finding their own uniforms and horses. After their year of service they pass to the reserve, and subsequently to the 1st and 2nd Ban of the Landwehr and the Landsturm. It is from this category of men that the bulk of the reserve officers are obtained. Three and four-year volunteers are men who join the army, meaning to make it their profession, and with a view to becoming officers or non-commissioned officers, as will be hereafter explained.

Officers are obtained from two sources, from the cadet corps and from the ranks, the latter category being much the larger. Boys, mostly the sons of officers, join the cadet houses, sort of preliminary schools, between the ages of 10 and 15, and are finally transferred to the Central Cadet Institution at Lichterfelde, near Berlin, where they remain for two and a-half years, and then, at the age of about 18, are appointed sword-knot ensigns, a few being commissioned direct as second lieutenants. Those who come from the ranks enlist, with the consent of the colonel, as three-year volunteers at 17 years of age. For the first six weeks of their service they live in barracks, but after that are generally allowed to have their own lodgings in the town and live at the officers' mess. They must either produce a certificate of a certain degree of education from a civil school or undergo an examination, and after five months' service they may receive a certificate from their company, squadron, or battery commander, testifying to their fitness for appointment to sword-knot ensign. On these two certificates they are gazetted to that rank. It should be distinctly understood that these officers are not from the ranks in our sense of the word. They enter, by permission of the commanding officer, with a view to becoming officers, and though they wear the uniform and do the duties of private soldiers, the fact that they are aspirants to commissions is fully recognized, and is testified to by their being admitted to the mess. From appointment to sword-knot ensign, the training of all is alike. This rank is intermediate between commissioned and non-commissioned rank, and the ensigns wear the uniform of non-commissioned officers with the officers' sword-knot, whence their name. On appointment to sword-knot ensign, the candidate is sent to a war school, where he undergoes a nine or ten months' course of instruction in military subjects, after which he passes the so-called officers' examination and is commissioned as second lieutenant. Officers of artillery and engineers are only temporarily commissioned at first, and, after 21 months' service with their regiments, pass through a course at the United Artillery and Engineer School at Berlin, lasting 5½ months for artillery, and 20½ for engineer officers, upon which their commissions are confirmed.

Non-commissioned officers come from two sources—from the non-commissioned officers' schools and from the ranks. The former are establishments where youths of 17 to 20 years of age are trained to be non-commissioned officers. Their course of instruction lasts three years, and they are bound to serve four years in the army. They are appointed non-commissioned officers direct from the schools, and a certain number of vacancies are kept open for them. Very few men of the annual contingent are promoted to non-commissioned rank, the great mass of the non-commissioned officers coming from three-year volunteers who enter with a view to making the army their profession. These must re-engage before appointment to non-commissioned officer, and must also pass through the "school for re-engaged men" formed in every regiment. After nine years' total service, non-commissioned officers gain the right to be transferred to the gendarmerie, and after 12 years' service to employment in the civil administration. Bonuses on leaving the army are also provided for non-commissioned officers, rising in value according to length of service.

Reserve officers, as above mentioned, are obtained from one-year volunteers as a general rule. At the end of their year they pass the "Reserve Officer Candidate's Examination," and in the next two years have to undergo two trainings of eight weeks each, after the first of which they pass their officers' examination. In the first training they do non-commissioned officer's duty, in the second officer's duty, and on the conclusion of the second are appointed reserve officers. They must serve at least three years as reserve officers, but with the exception of this condition they are transferred as officers to the 1st and 2nd Bans of the Landwehr with men of their own class of age. At their own request, however, they may serve on as reserve officers without passing into the Landwehr. They are posted to regiments and promoted along with the officer immediately junior to them on the active list.

The German army is organized in twenty army corps, each of which forms a little army in itself, with a perfectly-decentralized administration. These corps and the territory belonging to each are as follows (see *Plate*) : –

Guard Corps.	Berlin.	Prussia and Alsace-Lorraine.
1st.	Königsberg.	East Prussia.
2nd.	Stettin.	Pomerania.
3rd.	Berlin.	Brandenburg.
4th.	Magdeburg.	Prussian Saxony.
5th.	Posen.	Posen and Lower Silesia.
6th.	Breslau.	Silesia.
7th.	Münster.	Westphalia.
8th.	Cologne.	Rhineland.
9th.	Altona.	Schleswig, Holstein, and Mecklenburg.
10th.	Hanover.	Hanover, Oldenburg and Brunswick.
11th.	Cassel.	Hesse and Hesse Darmstadt.
12th.	Dresden.	Saxony.
13th.	Stuttgart.	Württemberg.
14th.	Carlsruhe.	Baden.
15th.	Strassburg.	Alsace.
16th.	Metz.	Lorraine.
17th.	Danzig.	West Prussia.
1st Bavarian.	Munich.	South Bavaria.
2nd ,,	Würzburg.	North and Rhenish Bavaria.

In each, the general commanding is the commander of the territory and the superintendent of all recruiting and mustering operations, as well as commander of all the active troops, and is only accountable to the Emperor direct (except in the case of the Saxon, Württemberg and Bavarian troops).

commanded by captains (mounted), with, in peace, three, and in war, four lieutenants, regiments on the increased establishment having four lieutenants in peace also. There are three establishments for infantry. On the highest one are 33 regiments (nine of the guard and 24 on the French frontier), with 22 officers and 654 men per battalion; on the medium establishment, 14 regiments on the Russian frontier with 18 officers and 584 men per battalion; and on the lower establishment the remainder of the army with 18 officers and 560 men per battalion. The war strength of a company is 5 officers and 255 men, of a battalion 22 officers and 1,030 men, and of a regiment 68 officers, 3,107 men, 143 horses, and 44 carriages, all two-horsed.

German regiments are numbered in series, and bear their regimental number on their shoulder-straps. Most regiments have also a provincial designation, and many have the name of princes or distinguished German generals. In the latter case they are always known by those names, and not by their numbers. The uniform is dark blue (light blue in Bavaria) tunics, with black (light blue in Bavaria) trousers and red facings. The shoulder-straps and the piping on the cuff vary according to the army corps. The head-dress is the well-known pickelhaube, and the belts are black (except for the guards and Prussian grenadiers). The arm of the infantry is the 1888 rifle, calibre, ·309 inches, loading by packets of five cartridges, bolt-action breech-piece, jacket round the barrel. The bayonet is a long sword-bayonet, the short bayonet at first issued having been withdrawn. The rifle is sighted up to 2,050 mètres. The man carries 150 rounds. Forty more are carried for him in the company ammunition wagon, and 80 in the ammunition columns attached to the corps, making 270 rounds in all. Each battalion has 400 spades, 40 picks, and 20 hatchets, carried by the men, besides larger tools in regimental transport.

Rifles.—Of the 19 battalions, 2 are Prussian guard, 12 Prussian, etc., line, 3 Saxon, and 2 Bavarian. These battalions are organized exactly the same as infantry battalions, and are recruited as far as possible from picked shots, keepers, foresters, etc. Their peace and war strengths are very much the same as those of infantry battalions, n peace four being on the higher, one on the medium, and the remainder on the lower establishment. The four first-named battalions are stationed in Upper Alsace as a sort of counterpoise to the French mountain chasseur battalions. The uniform of the rifles is dark green with red facings (black in Saxony), light blue with green facings in Bavaria. In Prussia and Saxony they wear shakos, but otherwise they are equipped and armed like the infantry.

Cavalry.—The 93 regiments are furnished as follows:—73 by Prussia, 10 by Bavaria, 6 by Saxony, and 4 by Württemberg. As regards arms, they are sub-divided as follows:—

14 heavy regiments (cuirassiers, carbineers, or horse).
25 lancer regiments.
28 dragoon regiments.
6 light dragoon regiments.
20 hussar regiments.

A regiment is commanded by a major, lieutenant-colonel, or colonel, assisted by a second field officer, and consists of five squadrons commanded by captains. Twelve regiments (on the French frontier) have each 25 officers, 711 men, and 764 troop horses; 35 others (on French and Russian frontiers), 25 officers, 681 men, and 744 horses; and the remainder 25 officers, 666 men, and 729 troop horses. In war, one of the squadrons, determined by roster, is broken up, and its men distributed among the others, which can thus at the shortest notice be placed in the field. The war strength of a regiment is only 23 officers, 663 men, and 661 troop horses, so it is apparent how thoroughly the immediate mobilization of the German cavalry is ensured. It is impossible to go in general terms into the uniforms worn, as they are very varied, and there are so many exceptions to the rules. The arms of the German cavalry are, throughout the whole army, lance, sword, and carbine. The lance is of hollow steel, ten feet long, and has a flag of the national colours. The sword is carried on the person, and not on the saddle. The carbine is of the same calibre and construction as the infantry rifle, and is carried almost horizontally over the rider's right thigh, the muzzle fitting into a bucket on the off-wallet. Eight men per squadron are trained and equipped as pioneers.

Field Artillery.—Of the 43 regiments, 2 are Prussian guard, 31 Prussian line, 5 Bavarian, 3 Saxon, and 2 Württemberg. To go into the details of composition of each would be impossibie within the limits of this lecture, and I have already given the typical and normal composition of the two regiments of an army corps. Of the total of 384 field batteries 260, and of the 47 horse batteries 22, have in peace 6 guns horsed, the remainder 4 guns only. Certain batteries on the frontiers have two ammunition wagons also horsed.

The battery establishments in peace are :—

6-gun, field,	4 officers,	111 men,	68 horses.
,, horse,	4 ,,	112 ,,	115 ,,
4-gun, field,	4 ,,	100 ,,	51 ,,
,, horse,	4 ,,	90 ,,	85 ,,

Thus it will be seen that the German batteries on the peace footing are kept at a considerably lower strength than our own. On the war footing, a field battery has 5 officers, 170 men, and 150 horses, and a horse battery 5 officers, 164 men, and 236 horses, both having 6 guns, 8 ammunition wagons, 1 forge, 3 store wagons, and 1 (2 in H.A.) provision (forage) wagon. The uniform of the artillery is similar to that of the infantry, but with black facings, and balls in place of spikes on the helmet. The gun is of an uniform calibre for both horse and field artillery, viz., 9 centimètres, or 3·465 inches, on Krupp's system, with a cylindro-prismatic wedge and Broadwell ring, firing common shell weighing 15lbs. 7ozs., shrapnel weighing 16lbs. 9½ozs., and case shot. The powder in use is flake smokeless powder. In the limbers are carried 15 common and 15 shrapnel, in the wagon body 20 or 25 common and 25 or 20 shrapnel, and, including the first echelon of ammunition columns, each gun has 191⅚ rounds available for an action. The gunners are armed with revolvers and sword-bayonets, the drivers with cavalry swords. Pole-draught with collars is in use in the artillery, and the harness of lead, centre, and wheel horses is interchangeable.

The *Foot Artillery*, with the exception of one regiment, is exclusively trained as siege artillery, and is organized in 14 regiments of 2 battalions each (11 Prussian, 2 Bavarian, and 1 Saxon), and 3 independent battalions (2 Prussian, 1 Württemberg). Of the 31 battalions (each of 4 companies), 10 are on the increased footing of 4 officers and 158 men, and the remainder on the normal footing of 4 officers and 122 men per company. In war, each company has 4 officers and 209 men. The foot artillery have the same uniform as the field artillery, but with white instead of scarlet shoulder-straps, and the men are armed with carbines and sword-bayonets.

Engineers.—Of the 20 pioneer battalions, 16 are Prussian, 2 Bavarian, and 1 each Saxon and Württemberg. The battalions have 4 companies each, except in the guard battalion, which has an extra company of telegraphists, and in the 2 Bavarian battalions, which have 5 companies each. The first three of each battalion are trained as field engineers, the remainder (one or two) as fortress engineers. Each company (in Prussia, others are slightly different) has, in peace, 4 officers and 125 men. On mobilization each pioneer battalion forms 3 field companies (one attached to each division and one to the corps troops), 2 divisional bridge trains, 1 corps bridge train, and 2 siege companies, besides reserve formations. A field pioneer company has 5 officers, 213 men, 88 horses, and 14 carriages. The divisional bridge train carries 120 feet of bridge (6 pontoons and 4 trestles), and the corps bridge train 396 feet (26 pontoons and 6 trestles). The uniform of the pioneers is the same as that of the field artillery, but with white instead of yellow buttons, and spiked helmets. Their armament is the same as that of the infantry.

Telegraph sections are formed on mobilization, one for each army corps, with $23\frac{1}{2}$ miles of line, of which $15\frac{1}{3}$ are air line and 8 cable.

The railway troops consist of 2 Prussian regiments, of 2 battalions of 4 companies each, and 1 Bavarian battalion of 2 companies. Each company in Prussia has 5 officers and 122 men; in Bavaria, 8 officers and 153 men. These, together, in war, mobilize 9 construction, 18 traffic, and 5 workmen companies, with the details of which it is needless to trouble you.

The Prussian balloon detachment consists in peace of 5 officers and 50 men, the Bavarian of 3 officers and 30 men, but nothing is known of their war formation.

The Train is organized on the principle of keeping in peace the smallest possible cadres, which can be rapidly expanded on mobilization. There is one battalion to each army corps, and a separate battalion for the Hessian division, giving 21 in all, and these vary in strength, the typical battalion having in peace three companies with in all 14 officers, 315 men, and 192 horses. In war, each such battalion would form :—

5 provision columns (carrying four days' rations),
5 wagon-park columns (to fill up the provision columns),
1 field bakery,
3 bearer companies,
1 horse depôt,
1 L. of C. wagon-park column,
1 L. of C. bakery column,

and these, exclusive of the two latter, give, together, a total of

20 officers, 1,903 men, and 2,049 horses, so it is evident how great is the expansion. Men for the transport of various staffs, of the field hospitals, and of the siege train, are also found by the train. The uniform is dark blue with light blue facings.

Before passing to the war formation of the army, one word as to the superior administration. There are two authorities directly under the Emperor, and equal in rank, the War Minister and the Chief of the General Staff, each of which has his own staff. The duties of the former are, roughly speaking, the administration of the army in peace, and its preparation for war and mobilization; those of the latter, the conduct of the army in war, and the preparation in peace of plans of campaign. The General Staff is recruited solely from officers who have passed through the staff college, and is the highest trained body of officers in the world. It numbers some 250 officers, of whom about half are employed at headquarters, the remainder being detached, one to each division, and three to each corps staff.

On mobilization, the units of the standing army are mobilized as they stand in peace, except that only one cavalry brigade is left to each corps, the remaining brigades being formed, with horse artillery, into independent cavalry divisions of three brigades—six regiments with two H.A. batteries. There would thus be in war 20 army corps and nine cavalry divisions.

In addition to these, each infantry regiment would form a fourth and a depôt battalion. The latter remains in the garrison of the regiment, and supplies it with drafts; the former either is sent with or after the regiment, or is used to garrison fortresses, or hold the posts on the lines of communication. Depôt formations are similarly formed by the other arms.

As second line come the so-called reserve troops. These would be formed by the regular regiments, each infantry regiment forming two battalions, each cavalry regiment one squadron, the artillery brigade of the army corps six batteries, the pioneer battalion one company, and the train the necessary services. Cadres for these are given by the standing army, and the men come from the Landwehr of the 1st Ban, so that we thus at once get 20 divisions (1 per army corps), each formed of 16 battalions, 4 squadrons, 6 batteries, and 1 pioneer company, available for sieges, work in second line, or even to reinforce the field army, as was the case in 1870.

The third line is composed of so-called Landwehr troops, formed of men of the 2nd Ban of the Landwehr, and these also will probably form a division for each army corps; but the divisions will hardly be so strong as the reserve divisions, and will vary in strength from 12 to 16 battalions, with probably only 2 squadrons, 3 batteries, and a pioneer company. They are only likely to be used on the lines of communication or in garrisons.

Thus the German army on the war footing will comprise:—

1st line—20 army corps,
9 cavalry divisions,
2nd line—20 reserve divisions,
3rd line—20 Landwehr divisions,

besides depôts, etc.

It is extremely difficult to arrive at an idea of the war strength in men of the German army, but I do not think we shall be far wrong if we take Prince Bismarck's estimate of two millions in the field and a million more at home.

LECTURE II.

Training and Tactics.

It is hardly necessary to point out that in the German, as in all other Continental armies, the training of the men is very much simplified by the fact of all the recruits joining on one day, and thus a plan of instruction can be laid down with a regularity and carried out with a thoroughness unknown in our army, whose recruits join daily. The absolute fixity of effectives and rarity of changes of garrison also tend to prevent any disturbances in the scheme of instruetion. This system is the result of years of experience, and has now grown into the flesh and blood of the German army. The one great principle underlying the whole is the absolute responsibility of the commanders of companies, squadrons, and batteries for the instruction of their men, and as long as their methods lead to the desired end, their superiors never interfere with them. A German is nothing if he is not thorough, and the basis of the whole wonderful instruction of the German army is the careful individual teaching of each man by his officers, who labour away at their task, proud of their position as the schoolmasters of the nation in arms, and ever mindful of Kant's categorical imperative "Pflicht und abermals Pflicht"—duty and again duty. And not only does this instruction extend to the bodies of the men, but also to their minds—drill progresses alongside of education. By lectures and conversations the German officer instils into his men patriotism, devotion to the Sovereign, and religious feeling, all the factors which go to make up the motto worn on the helmets, "Mit Gott für König und Vaterland." There is a great deal of what I should imagine the old Puritan spirit to have been to be remarked in the German army, and every care is taken to foster this. Every night, in camp or bivouac, after the tattoo the evening hymn is played, the men standing bare-headed the while, and surely it was the old Puritan spirit which blazed out when, on the evening of Sedan, after the great battle which laid Germany's hereditary enemy at her feet, from that great circle of conquerors, flushed with victory, there arose from hundreds of bands, and from tens of thousands of voices, the hymn of thanksgiving, "Nun danket alle Gott." It is this earnestness of purpose, this devotion to duty, which has made the German army what it is—the finest fighting machine in Europe.

In the infantry, the recruits join in the first week of November, each battalion receiving from 190 to 244, according to its establishment. Thence onward, the year is divided into periods which are roughly as follows :—

November to 1st March.—Recruit drill, individual instruction.

1st March to 30th April.—Company drills.

1st May to 31st May.—Battalion drills.

1st June to 31st July.—Field service (minor tactics).

1st August to beginning of September.—Regimental and brigade drills.

September.—Manœuvres and departure of the recruits.

Each of those periods must now be considered separately.

In each company an officer is selected specially for the charge of the recruits, and under him are placed four or five under-officers and the same number of lance-corporals. In the interval between the departure of the reservists in September and the arrival of the recruits in November, he puts those through a special course of instruction, so that they are fully prepared as instructors. Needless to say, they are carefully selected. Each company receives from 50 to 60 recruits, and these are divided into four to five squads, under the under-officers, so that two instructors have more than 10 or 12 men to look after. It is a common error to suppose that the German officer himself goes through the task of teaching the recruit his drill by motions. He does not do so, but only superintends. At first the men are worked lightly, but gradually the hours are increased to three in the morning and two in the afternoon, with an hour's theoretical instruction in the evening. The first object of the instructor is to make his men supple and hardy, and with this view the "Freiübungen" or free exercises, are begun with first. These correspond in general to our new system of extension motions, and when the recruits have attained to some proficiency in them, squad drill is begun. Gradually gymnastic exercises with the rifle, and later on gymnastics with appliances, are introduced, marching and squad drill still proceeding, and it is only in the fourth week that the recruit begins to learn the use of the rifle. Skirmishing is begun very early in the course, every man being most carefully taught how to take advantage of cover, and by about the seventh week the man begins to shoot with aiming ammunition. Guard and sentry duty is practised in the square in the last weeks, and about the 1st March the recruits are "presented" by the captain of the company to the commander of the regiment. Quite a small *fête* is made of this occasion, and all the officers of the regiment are present. Next day the recruits are placed in the ranks of the company. During this period the older soldiers perform all guard and fatigue duties and perfect their instruction under the other officers of the company.

In March and April come the company drills. The men are sized and told off into sections and squads, the recruits being as far as possible equally distributed; a further distribution of the men is made into three classes according to their intelligence and proficiency, and these classes are drilled separately when the company is not being drilled as a whole, to perfect their individual instruction. At the beginning of the period a few route marches are made, the weights carried being augmented progressively, and hints are given as to precautions as to blisters, care of feet, etc. At first the company is drilled on a flat parade ground. As the company is the foundation of all things, the very greatest importance is attached to this period, and every care is taken to make the company thoroughly handy. Paragraph 143 of the drill regulations is printed in special type and runs :—"The company must be so trained that it always remains in the hand of its leader, and, with absolute attention to his orders, can execute even movements which have not been previously practised." Frequently the companies are drilled without officers or N.C.O.'s, frequently they are broken up and rallied in a new direction, and the most absolute precision and smartness is exacted from all ranks. Skirmishing and the attack are practised first on the flat and then on broken ground, and everything is done with a care and patience really admirable. I think I am not wrong in saying that the German infantry is the quickest in its manœuvres in Europe, and that this is almost entirely due to its practice in this period of company drill.

In May, the battalions are drilled as such about three times a week in the forenoon, and on the remaining days company drill and musketry are carried on, the afternoons being devoted to gymnastics, bayonet exercise, aiming drill, and swimming. At first the battalion is simply drilled in parade movements, but afterwards it is taken into broken ground and practised in all possible formations.

The period of field service, *i.e.*, training in minor tactics, is not so strictly defined as the others, and usually begins before the battalion drills cease. Company and battalion drills, gymnastics, and swimming still go on throughout. At first the companies go out singly, but afterwards they are practised against one another, and in July battalions and even larger units are placed under one command. All branches of minor tactics, such as advanced guards, outposts, attack and defence of localities, scouting, reconnoitring, field fortification, etc., are practised, and everything is done most carefully and progressively.

In August, the battalions of a regiment are usually concentrated in the same garrison, if not already there, for seven days' regimental drill, of which two are on broken ground, after which the brigades are put through five days' brigade drill, artillery being often added to the infantry for one or two of them. The movements performed are invariably very simple.

Before proceeding to consider the manœuvres, mention may here be made of the inspections and of the musketry practice. The principle of the inspections, which come at the close of each period, is that they should interfere as little as possible with the course of instruction, and that no unit should be inspected twice in the same subject. The present Emperor's order on this subject dated 31st March, 1889, is well worth quoting here. It runs:—

"The manner of inspection is of decisive influence on the instruction and training of the troops. Too many inspections are hurtful; where their object can be obtained without special days for inspections being set apart, time should in this way be saved. Inspections of the same branch of military duties, closely following one another, and by different superiors, are to be avoided by timely agreement amongst the latter.

"Future inspections must take the various branches of instruction into consideration, according to their importance for the training of the troops. If by their time and style importance is only given in a one-sided manner to the formal training of the troops, the leaders of the latter will be led astray as to the higher branches of their duties, and their capacity will not be properly estimated. Their yearly visits to garrisons are to be so timed by higher commanders that they may be enabled to gain a thorough idea of the state of training of the troops under their command for war in all the phases of that training. I shall see from the reports before me whether the inspections have been carried out in this way.

"Finally, I order that, at all inspections in battle-training, an exercise is to be prescribed by the inspector to the commander of the troops, and that, as far as the limits of the ground allow, the enemy is to be marked. Every day of inspection will then be a real day of instruction for the troops."

"(Signed), WILHELM."

As troops are inspected, so they are instructed, and the above golden words breathe the essence of the German system of instruction.

Musketry instruction goes on all the year round except at the time of the autumn manœuvres. In winter, target practice is carried out twice a week, but from March musketry instruction is pushed on as rapidly as possible, so that most of the men have finished their course when the field service period begins. The men are divided into three musketry classes, the third comprising the recruits and the bad shots, the second the better shots, and the first the marksmen. The range practices can be got through in the third class in 50, and in the second and first in 44 rounds. Ninety rounds per man are allowed for field firing, and the rest of the ammunition assigned to a company is used to improve the worst shots, etc. The maximum ranges fired at by third-class shots are 400, second-class, 500, and first-class 600 mètres. Time will not permit of my entering deeper into the subject of musketry, which, like every other branch of training, is most carefully and methodically taught.

We have now accompanied the German infantry soldier from the date of his entry into the service up to the beginning of his first autumn manœuvres. Time prevents my alluding to the training of the other arms further than to say that the same regular system of instruction, proceeding gradually from the simple to the difficult, is pursued, and the same results attained. We shall now proceed to the autumn manœuvres, which form the crowning of the annual training of every member of the army, and which are with justice looked upon as the real training of the army for war. To these manœuvres all units march out at the complete peace establishment, sufficient reserve men being called in to fill up the places of men left behind in the garrisons for guard or fatigue duty.

The manœuvres last ten working days, that is, exclusive of days of rest and Sundays. For the first four, each brigade of infantry is divided into two portions, details of the other arms being attached to each, and these manœuvre against one another under the direction of the brigadier-general. To these succeed four days of manœuvres of the brigades of a division against one another, cavalry and artillery being attached to each, under the direction of the divisional commander. Lastly come two days of manœuvres of the divisions against a supposed or masked enemy. This is the ordinary programme, but it may be modified at the discretion of the corps commander. An allowance of straw, firewood, etc., is made for $4\frac{1}{3}$ bivouacs for each officer or man engaged in the manœuvres, but when not in bivouac the troops are billetted on the inhabitants. Certain army corps are each year selected for manœuvres before the Emperor. In this case the first two periods (detachment and brigade manœuvres) are reduced to three days each. Then comes a grand parade before the Emperor, the manœuvre of the whole corps against a masked enemy, and three days manœuvres of the whole corps against another corps. In this case a cavalry division is usually attached to each corps. These manœuvres are made as near an approach to actual warfare as possible. Outposts are invariably thrown out and everything is done as in war. After the manœuvres the troops march or are railed home to their garrisons, and the recruits who have completed their time are at once discharged. Short periods of leave are given to officers and N.C.O.'s, but in November the recruits come again, and again the same programme is begun. We now pass to the tactical forms.

The normal formation of the German infantry is the company column. Each company is divided into three sections or Züge of equal strength, and in company column these are placed in rear of one another at seven paces from front rank to front rank, each section being in two ranks. The formation in line is also recognized for the company, but not, except for parade purposes, when it is an unit in the battalion. Company square still is recognized, and is formed from company column by the second Züg wheeling outwards and the rear Züg closing up, but it is seldom practised. The battalion has only three formations—broad column, in which all four company columns are alongside of one another; deep column, in which they are in rear of one another; and double column, in which two are in first and two in second line, the distance between lines being seven, and the interval between companies three, paces. The whole of battalion drill consists of assumptions of one of these formations from the other.

There is no such thing as a normal form of attack, and only general principles are laid down in the drill book for the conduct of infantry in action. At first no more men are extended than are actually required for action, and all formations of an unit tend to depth rather than breadth. No body of troops is extended until it is compelled to do so by the enemy's fire—a principle the observance of which would have saved us the battle of Isandhlwana—and all closed bodies, when under fire, move in step, drums beating, this being done with a view to keeping the men in hand. Formerly the company column was the formation in which all troops in rear of the shooting line moved, but of recent years the introduction of smokeless powder, and small-calibre repeating rifles, has driven the company column from the field, and nothing is now seen but lines upon lines of deployed companies. Volley firing is never used, as it is considered to be impossible in war, and all firing is individual, the men being trained to aim and fire carefully. Advances of the shooting line are made in quick time and by large units, the idea being that running only pumps the men, and that small units advancing have difficulty in preserving their direction, and so mask the fire of the other small units in their rear. On the whole, the attack of German infantry has a wonderful air of dash and energy. In front comes a shooting line, becoming gradually stronger and denser as the enemy is approached. This line advances steadily as if it meant to close at any cost, then halts and pours in a murderous fire, only to be stopped by the officers' whistles previous to the resumption of the steady advance. In rear come line upon line of supports and reserves, gradually closing up on the shooting line as the enemy is neared and marching in step with drums beating and bands playing the regimental marches. We may think all this theatrical and impossible, but it is done of deep purpose aforethought, and the German soldier is taught to believe that victory lies forward, and that his object is to close with his enemy as soon as possible.

The cavalry formations are naturally much more varied than those of the infantry. The squadron is divided into four troops or Züge of at least ten files, commanded by officers. These are again told off by threes and twos, and the usual marching formation is by sections of three (three abreast). A squadron may be formed either in line, in column of troops at wheeling distance, in half column (assumed from line by a half wheel of troops to a flank), or in column of threes or twos. A regiment may be formed either in line or in line of squadron columns at full (deploying) or close interval, or in various modifications of those, into which it is impossible in the time at our disposal to enter. Brigades of cavalry would be composed of two regiments, and divisions of three brigades with two batteries of horse artillery and a detachment of pioneers carried in carts. We have all read of the probable employment of cavalry in masses in the battles of the future, and nowhere is this belief more firmly held than in the German army. As in the infantry, so in the cavalry, the offensive at any price is the guiding idea, and this has been accentuated of recent years by the arming of the whole of the cavalry with the lance, that essentially shock weapon. For employment either against cavalry or infantry, a cavalry division would be formed in three lines, but in each case the composition and formation of their lines would differ materially. Against cavalry, the success at first of the first line is held to be everything, and consequently in it would be placed at least half the force, riding in line and knee to knee. Half of the rest would be in second line about 300 paces in rear of the most exposed flank, formed in line of squadron columns at deploying interval, while the other half would form the reserve at 450 paces in rear of the other flank in line of squadron columns at close interval. Against infantry or artillery, the three brigades of a division would probably be placed in line in rear of one another at 300 to 400 paces distance, riding at open files with a view to breaking the strength of their adversary by a series of successive blows.

Field artillery formations and tactics are much the same in Germany as with us, but in general it may be said that formations are all at close interval. Generally, a battery in line only opens to full interval before going into action, and column of sections at full interval is unknown, a column at close interval being invariably used. Horse artillery detachments invariably ride in rear of their guns. The principles which govern the handling of batteries in action are well-known to you all, and need hardly be recapitulated here. I will only mention two points which I noticed in recent manœuvres, and which, so far as I know, have not been tried in England. One is the placing of batteries in lines in rear of one another (terraced fire) when the ground permits, and the other is the adoption of half interval as a formation for action. Both these have probably been necessitated by the great increase in the number of guns now taken into the field, and the consequent difficulty of finding positions for them all.

To sum up, I think I am justified in saying that the present tactical methods of the German army are the result of a most careful study of the lessons of modern war by the most highly-trained body of officers in Europe, and that its system of training is that best adapted to fit it for carrying out these methods.

PAPER III.

NOTES ON LAND AND COAST FORTIFICATION.

By Captain E. R. Kenyon, R.E.

INTRODUCTORY.

In this paper an attempt has been made to bring together the general principles governing the design of land and coast fortifications, and the principal data, both as to armament and works, which have to be considered when preparing a general design. It is not intended to describe any system of fortification in minute detail, and to recommend its adoption in all cases, but rather to deal with the principles on which a scheme should be prepared, to describe the steps by which designs must be worked out, to show the leading features of such designs, and to call attention to all the points which have to be considered, so that the general idea of a design can be intelligently prepared or discussed. For the preparation of the design in detail, a vast number of special arrangements and dimensions have to be considered, and for these reference is made to Major Lewis' book, *Fortification* *for English Engineers.* Some other portions of the subject also, which are treated at length by him or by Major Clarke in his *Fortification: Its Past Achievements and Future Progress*, are here only slightly mentioned, a reference being made when necessary to their writings. The references are indicated by the initial letters L. or C., followed by the number of the page in the editions of 1890. Many of the illustrations of gun-mountings have been reproduced from the diagrams published by Lieut.-Colonel J. W. Savage, R.E., in Vol. XVI. of the *R.E. Professional Papers* (1890).

E. R. KENYON, Capt., R.E.

Chatham, 1892.

CHAPTER I.

Use of Fortresses and General Principles of Land Fortification.

Use of Fortresses.—Fortresses may be required (1) to secure important lines of communication, *e.g.*, Verdun, which bars the road from Metz to Paris, and where several important roads and railways converge; (2), to serve as bases of operations, and, therefore, to be large depôts, and very often entrenched camps, *e.g.*, Metz; (3), to protect arsenals, dockyards, coaling stations, etc.

These three classes, or modifications and combinations of them, will be found to include all properly-placed fortresses. Thus fortresses to secure bridge-heads belong to the first class. Those in the interior of a country, *e.g.*, Antwerp or Langres, may be in the second; while those belonging to the third, *e.g.*, Portsmouth, Toulon, and Cherbourg, may often also fulfil the duties of the second class. Capitals, *e.g.*, Paris and Bucharest, will often unite all three classes.

Those of the first class may be quite small forts if the country is favourable, as in mountainous districts, *e.g.*, Ali Musjid in the Khyber Pass, or the two forts of Bard which block the approach to Italy over the Little St. Bernard. Those of the second must usually cover a considerable area, while those of the third may vary from works of the smallest to those of the greatest extent.

In each case the strength and extent to be given to the works must be calculated not only in accordance with the importance of the place, but still more with a view to the *reasonably probable strength of the attack* to which it may be subjected. For instance, a coaling station which lies close to a great naval port of a possible enemy must be much more strongly protected than one which is in no such dangerous proximity. Again, Paris requires extensive fortifications, because it lies within a few days' march of the German frontier. London needs no such works, because it cannot be seriously attacked until the fleet, our first line of defence, is completely overpowered. In fact, in England any *land* defences are really of the nature of retrenchments, the main fortification consisting of our navy, while the *coast* defences may be looked on as works on the lines of communication, covering stores and depôts, and in some cases furnishing bases of operation.

Land Fortresses.

It is unnecessary here to consider in detail the case where a single fort is sufficient. Such cases must be dealt with as they arise, in accordance with their own special circumstances. The *principles* to be adhered to are the same as for larger places, but the mode of their application may vary greatly.

Modern First-class Fortress.—A modern first-class fortress consists of a girdle of detached works round the place to be defended, with, usually, a continuous inner enceinte, which, being a survival of older fortification, is of more antiquated style.* This enceinte is, however, generally maintained, as giving security against any attempt by an enterprising enemy to push between the intervals of the forts. Whether it really fulfils this object, and whether in new fortresses an enceinte should be included as part of the design, are questions on which there is some difference of opinion When the works already exist, and can be maintained without great cost, it seems wise to preserve them, but it is exceedingly doubtful whether in any new fortress it would be worth while to incur the great expenditure which would be involved in building an enceinte. The money thus spent could probably be far more usefully employed in increasing and perfecting the means of communication, the security of magazines, the mobility of the armament, and the amount both of direct and indirect fire

Detached Works.—The detached works hitherto built are for the most part designed for a powerful artillery fire, combined with a certain amount of musketry, and their armament usually consists of from 8 to 20, and occasionally even 50 guns, with garrisons varying from 400 to 1,000 men. There is, however, much controversy as to the proper mode of fortifying a place, and various systems have been proposed. At one extreme we have systems of

* Some German fortresses have, however, been furnished with new enceintes since 1870.

which the main features are forts armed with heavy guns in fixed or revolving iron or steel cupolas, and lighter pieces in disappearing cupolas, the cupolas themselves being embedded in heavy masses of concrete, in which are also the necessary magazines, casemates, etc. At the other extreme is a system of mere infantry redoubts, with artillery emplacements outside, into which the guns may be moved as required, the whole armament (except, perhaps, some mortars and howitzers) being on travelling carriages. In this system the infantry redoubts, of course, include casemates for the garrison, but the magazines, etc., are placed in such positions as may be convenient. Between these two systems there are numerous variations, some of which are mentioned in Chapter VI.

General Brialmont's *Influence du tir Plongeant* and *Les Régions Fortifiées*, and Major Clarke's *Fortification: Its Past Achievements and Future Progress*, should be carefully read.

General Nature of Defence.—Whatever system be adopted, the line of forts marks that fighting position which the defender must hold to the last. Sooner or later it is inevitable that the besieger (unless he is content with a mere blockade) should overpower the artillery of the defence. He probably will not be able to silence it altogether, but he must obtain a marked superiority, or abandon all ideas of an active siege. Hence the ultimate defence rests on the rifle fire which can be delivered against a close attack, all artillery which has not been previously destroyed being a most valuable auxiliary to this fire.

Rifle Fire.—The main object of the scheme of defence is to prevent the enemy penetrating the position in force, and it is clear that this must be attained by providing efficient rifle fire.

Artillery Fire.—The second object is to keep the enemy at a distance as long as possible, and to make his advance to the close attack as slow as possible. This can only be fulfilled by providing effective artillery fire to sweep as great an extent as practicable of the country in front, especially the main lines of approach and all favourable fighting positions. To overcome this artillery, and also to produce any serious effect on the casemates where the infantry are sheltered until their fire is needed, the besieger must bring up siege guns and material.

Advanced Infantry Position.—A third object is to prevent the enemy from occupying those points which are most favourable for the construction of his siege batteries. To some extent the guns of the fortress will themselves achieve this object, but it may be still further secured when the garrison is strong and active by the occupation of an advanced infantry position, which, receiving support from the fortress guns, may be rendered so strong that the besieger cannot capture it until he has brought up, at least, the lighter pieces of his siege train. When the country in the neighbourhood of the fortress is close, such an advanced position may be of the very greatest importance, on account of the additional delay caused to the siege; but when it is open, the fortress guns will themselves keep the besieger at such a distance that it is improbable that anything would be gained by forming an advanced infantry position. In British possessions it is probable that garrisons would seldom be of sufficient strength to enable them to go beyond the line of the forts, for unless they were strong enough to hold the advanced position for a reasonable period, its brief occupation would merely cause useless loss of life and *morale*. The subject will, therefore, not be further considered here, but is fully dealt with in a paper by Von Brünner on *Studies in Fortress Warfare*, a translation of which appeared in the *R.E. Professional Papers* for 1884 (Vol. X.).

Preparation for War.—In order to fortify a place and prepare it for war, the following steps are necessary:—

1. During peace, the principal detached works should be prepared (except in those cases where special circumstances make it unnecessary to construct anything stronger than heavy field works, which may be made when war actually threatens); all ordnance for them and for the intervals between them should be mounted or stored in the immediate vicinity. All range tables should be prepared, and all magazines for the intervals, as well as for the main works, built and supplied.

It is not possible to lay down any absolute rule as to how many works must be built and armed in peace, and how much may be left to the outbreak of war. It is necessary that *sufficient* preparations should be made beforehand to ensure the works, with their ordnance and garrisons, being in their right places when wanted, and in the needful strength. What is sufficient preparation, and what is needful strength, will vary in different circumstances. If sufficient works are in existence to compel the invader to halt and lay siege to the place, the primary requirements of defence have been met.

2. All roads, tramways, or railways, as well as lines of telegraph, telephone, etc., required for perfect communication between the town

and detached works, between forts, redoubts, and batteries,* between ordnance and magazines, etc., etc., should be designed and, as far as possible, constructed in peace.

3. The exact position in advance (if any) to be occupied, the exact number required for each portion of it, and the particular troops to be told off, should all be determined in peace, and communications between the fortress and this position should, if necessary, be improved.

4. A complete scheme should be prepared, showing all steps that have to be taken to prepare the place for war, dealing with the following points :—

(*a*). The ordnance available, where they are to be mounted, the stores (such as platforms, etc.) and tools required, where they are, or how they are to be provided.

(*b*). The bombproofs, traverses, shelters, observing stations that have to be constructed or improved. Complete designs must be prepared, with tables showing materials and working parties required, and where they can be obtained. If possible, bullet and splinter-proof, or, at least, weather-proof, cover should be designed for observing stations. Where electric lights are to be used, it must be remembered that fog, and even very slight mist, seriously interfere with them, and that even under favourable conditions they cannot be relied on beyond 2,000 yards.

(*c*). Sites for intermediate works (batteries, magazines, redoubts, shelter trenches, etc.). These must be selected, and designs for them and their communications prepared. Tables showing tools, materials, and working parties required, and where they can be obtained, must be prepared. If possible, the tools and materials should be stored. No officer should be content with *type* designs, but the exact site for each work should be selected, and its design prepared in full detail.

(*d*). Similar designs and tables for barrack, camp, or hut accommodation for troops.

(*e*). Similar designs and tables for all necessary roads, railways, telegraph lines, etc., not already constructed (see 2). It may some-

* Throughout these notes the word "Fort" will be used for works designed for powerful artillery and infantry fire; "Redoubt" for those in which the rifle is the sole, or at least the principal, arm, artillery being either not provided for at all, or only supplied with one or two emplacements for occasional use; and "Battery" for a work providing artillery fire alone, or, at most, supplemented by a small amount of infantry, acting practically as escort to the guns.

times be necessary to prepare for a regular system of covered roads like siege approaches, to enable troops to move to the support of advanced posts and batteries, or even to the ordinary detached works.

(*f*). The methods and materials required for any demolitions of railways, etc., which the enemy might use.

5. On the receipt of the order to "prepare," the work detailed in 1, 2, and 3, if hitherto neglected, must be carried out, and the scheme prepared under 4 must be put in force as far as may be necessary. On the front threatened, it should be carried out in its entirety. Elsewhere it may be wholly, or partially, suspended. The directions of the lines of march of the investing columns will probably give some clue at an early period as to the side where the attack will be most pressed.

6. The ground in front of the advanced position, or of the works, as the case may be, must be cleared.

7. Necessary demolitions must be effected.

8. Houses, villages, woods, etc., in the fighting line must be prepared for defence.

CHAPTER II.

General Arrangement of Land Works.

General Line to be Occupied.—The general scheme of defence for any large land fortress would, in ordinary circumstances, be to place the detached works so that the besieger cannot effectively bombard the town or depôts to be protected until he has captured one or more of them. The first point, then, to be decided is the general line to be occupied by the works, for this is the main fighting line of the defence, whatever advanced positions or inner retrenchments may be added. If an enceinte exists, it cannot be looked on, at best, as anything more than a retrenchment which may cause a slight prolongation of the siege. In most cases it would probably not even serve this purpose.

In some places the forts may form a ring of fairly uniform strength, while in others, as at Paris, they may be arranged in several groups, each of which secures some great line of approach or other important feature, the whole being so designed and connected that the enemy cannot pass in force between any two groups, but must attack one or more. Similarly, the distance of the forts from the place which they protect may vary greatly, both according to the importance and nature of the place and the character of the country, Where a large civil population has to be secured from bombardment, the forts must be on a much greater radius than where troops and military stores, etc., in bombproof cover have alone to be considered.

Circumference Occupied by Existing Forts.—The forts at Paris, in 1870, were on a circumference of about 30 miles; that on which the new groups of forts now stand is over 70 miles, and if all the proposed works are constructed, it will be extended to about 90. At Toul, the circumference is about 27 miles; at Epinal, 36; at Verdun, 25; at Antwerp, 50; at Bucharest, 43.

Distance from Enceinte.—At Paris, some of the individual forts are 10 miles from the enceinte ; at Verdun they are 4 miles from it ; in Germany they are usually from $1\frac{3}{4}$ to 3 miles out ; and at Bucharest (which has been very recently fortified upon General Brialmont's designs) they are from $5\frac{1}{2}$ to 8 miles from the enceinte. Probably four miles from the enceinte, or rather from the exterior of any buildings, etc., which have to be protected from bombardment, may be taken as a distance which would generally be considered sufficient, but each case must be dealt with on its own merits.

How to Occupy the Fighting Position.—Having thus determined the general line to be held as the main fighting position, the next point is to decide how to occupy it, and, to arrive at a direct decision, it is absolutely necessary that the tactical requirements of the case should be thoroughly grasped. It has already been pointed out that the ultimate defence of the place depends upon rifle fire, and although machine guns and shrapnel may be very useful auxiliaries, there can be no reasonable doubt that the infantry must be looked to to secure success. Works and guns are only intended to enable the defending infantry to maintain itself against all attacks. It is, therefore, essential that the infantry should be so placed that their fire shall be thoroughly efficient over the immediate foreground. On the other hand, guns must take the prominent share of the fight while the enemy is still at a distance. Their duty will be first to support the infantry in advanced positions (if such are taken up), and, by this combined action, to compel the enemy to form his line of investment at a considerable distance from the fortress. Next, they must delay him in his attacks on the advanced positions. If no advanced position is taken up, they have to assist the infantry in making a *coup-de-main* impossible. In either case, they have to interfere as much as possible with the construction of siege works, and to keep them at a distance. Finally, they should, if possible, take an active part in supporting the infantry when an assault takes place. To effect this last object, some or all of the guns must be able to fire on the immediate foreground, but for all the other duties it is quite conceivable that the posts which are best for the guns are not those which are best for the infantry. In any case, the infantry must be first considered and then the artillery, and great care must be taken to carefully separate in the mind the requirements of the two arms, and not to consider it necessary that either should be sacrificed to the other. Further, the requirements of the artillery for the distant defence must be carefully discriminated from those for the defence of the intervals between the forts and for the immediate support of the infantry during the close attack.

Tactical Pivots.—The next step is, therefore, to decide what points in the line must be occupied as tactical pivots for the infantry defence, and to design such works as will enable their defenders to develop at the right time the maximum amount of effective fire. The intervals between these pivots will have to be occupied in whatever way may be suitable to the ground. In some places no infantry may be needed; in others the natural features of the ground may be turned to useful account; and, in others again, artificial trenches and other works may have to be constructed. The artillery defence must next be dealt with, positions for the guns being selected which will enable them to fulfil the duties mentioned in the last paragraph. It *may* then be found that in some portions of the line the artillery and infantry must occupy the same site; and, in such a case, a fort containing gun emplacements and musketry parapets must be provided. More often it will appear that the best sites for the artillery are not coincident with those for the infantry, and then the pivots of the infantry position will be held by infantry redoubts, while the artillery will be furnished with suitable emplacements or batteries elsewhere.

Sometimes there will be more than one position equally suitable for a particular battery, but one of which must be occupied by infantry. The question then arises whether it is preferable to put the guns also in that position or not. It would probably be economical to do so, and it would certainly simplify the arrangements necessary in peace for the care of the guns, etc., but on the other hand, a larger target would be offered to the enemy, which might seriously injure the infantry cover by shells fired at, and missing, the guns. In fact, the presence of the guns would draw fire prematurely on the infantry defences. This might, perhaps, be risked in the earlier stages of the fight, but it would certainly be undesirable, for the sake both of guns and rifles, to retain the guns in the redoubt after the besieger's fire had become fairly accurate. Hence, if the guns are placed in the redoubt at first, their position there must only be regarded as one, and that not the most important, of their alternative emplacements.

Distance Apart of Forts and Redoubts.—In carrying these general considerations into practice, the question at once arises how far apart should the infantry redoubts be in ordinary circumstances?

Certain points there will always be, such as those commanding main approaches, etc., which *must* be occupied, but unless the ground is very strongly accentuated there may often be a doubt as to the number of redoubts required in order to secure the whole line with the minimum garrison. General Brialmont recommends an interval of 4,000 mètres between his main works, but these are massive forts armed with heavy artillery, and in the intervals he places batteries of howitzers and mortars, with armoured protection. At Bucharest, there are 19 forts from $1\frac{3}{4}$ to $2\frac{1}{2}$ miles apart. At Strasburg, the average interval is 3,540 mètres; at Cologne, 3,600; at Verdun, 4,500; at Toul, 5,000; at Epinal, 4,500. It is stated, however, that the general opinion on the Continent seems to be tending towards the construction of infantry redoubts at intervals of about 1,000 yards (see Chapter VI.). This seems a needlessly small interval, the chief argument in its favour being that then each redoubt would be more self-dependent, as it could completely defend almost, if not quite, the whole interval. We might, however, be contented with less security than this, and it would seem sufficient that each redoubt should be able to completely secure half the interval, while at the same time it could, with long-range rifle and machine-gun fire, afford effectual support to its neighbour. Each redoubt may be assumed to fully defend a space of 800 yards from its crest, and if its length is not less than 200 yards it will, therefore, defend 900 yards from its capital. Thus we arrive at 1,800 yards, or about a mile, as the normal interval between forts from capital to capital, which only slightly exceeds the distance over which ordinary long-range rifle fire is considered effective, namely, 1,500 yards. The *average* distance between the redoubts of any one fortress would probably exceed this amount, as there would usually be certain spaces which could be held more weakly, either because the natural features of the ground forbid the besieger to advance, or because lines of communication and other facilities for his operations are wanting. Thus the number of redoubts required for any large fortress might, perhaps, be roughly estimated by assuming their average distance apart to be from $1\frac{1}{4}$ to $1\frac{1}{2}$ mile.

Artillery in the Flanks.—The mutual support which the redoubts can give to one another will be increased if artillery fire can be added to that of the rifles, and it is, therefore, frequently urged that in the flanks of the redoubts there should be guns so protected by traverses, or in casemates or cupolas, that they cannot be silenced by the besieger's fire from a distance, and can, therefore, be maintained in serviceable condition for use against troops assaulting the redoubts or trying to penetrate the intervals. No doubt if guns could be thus preserved they would be of great assistance at the critical moment of assault, but to secure this preservation they must either be protected by extremely costly contrivances, or must be so placed that they cannot see or be seen from the front, and very often both the costly protection and the invisibility must be combined. Thus they are debarred from assisting in the earlier stages of the siege, and are, at great cost, so placed that they can be of no use unless an assault is made. A wiser policy would seem to be to expend the same amount of money in providing more guns, so mounted that they can be moved from place to place as required.

Artillery for General Purposes.—We now come to the wider question of artillery for general purposes. Its duties may be summarized as being to keep the enemy's investment line at a distance, to delay its closing in and the construction of siege works, and, in fact, to prolong to the utmost the preliminary operations which have to be undertaken before the besieger can come within striking distance of the infantry. The artillery should also be sufficiently powerful to make it impossible for an energetic enemy to carry the line of defence by a rush, even if the full strength of the infantry garrison is not present; or if, being of imperfectly-trained troops, they have not yet attained the full efficiency which a few weeks of active service may give them. This rapid rush upon fortified places is advocated by some distinguished officers on the Continent as the only means of avoiding the long delays, loss, and tremendous strain, inseparable from the siege of modern first-class fortresses; but it could only be attempted with any hope of success against very weak, or very imperfectly-trained, troops. If these contingencies are possible—and it cannot be denied that, for England, they might arise—the result must be guarded against by the presence of a sufficiently powerful artillery to secure the time that is required to complete the mustering and training of the garrison. Of what nature, then, must the artillery be? where shall it be posted? and how shall it be protected? To these questions very diverse answers are returned. On the one hand it is said that the ordnance should be as heavy as practicable, that it should be rendered secure against hostile fire by heavy masses of concrete and armour, and against assault by deep ditches, with masonry revetments, flanked by Q.F. or other guns. On the other hand it is urged that the accuracy of artillery fire, both direct and indirect, and the power of high explosives and of shells of very large capacity, are so great that the desired protection cannot be obtained except at prohibitive cost. Therefore, it is argued that the guns must be secured, not by concrete and armour, but by giving them as much invisibility and mobility as possible, so that the enemy may, from the first, find it difficult to ascertain where the guns are which he wishes to silence, and that when he has found them and his fire is becoming dangerous they may be readily moved to other emplacements previously prepared. Finally, it is added, that for the cost involved in the massive forts advocated by the other school of thought, many more mobile guns and all necessary communications and screens may be provided. There can be little doubt that ultimate victory will be on the side of the advocates of invisibility and mobility, and that land fortifications will follow the analogy of land armies, which have long ago discarded armour, finding it hopeless to provide it in sufficent strength to resist modern weapons. Thus we conclude that the guns must be the heaviest which can be mounted on travelling carriages, that they must be so posted as to be as nearly invisible as possible to the enemy, that they must be provided with alternative positions from which to fire, and that they must be secured against assault by infantry fire, assisted by obstacles.*

Howitzers and Mortars.—Howitzers and mortars can always be perfectly concealed, and mobility is, therefore, less essential for them. It will probably be useful to have some of them on travelling carriages, but advantage of their complete invisibility may be taken to utilize some of heavier natures on fixed mountings, and thus to regain some of the old superiority of weight of shell formerly possessed by the besieged, although in the case of the guns it must be relinquished until serviceable mountings, travelling on rails, can be devised for the heavier pieces.

Emplacements for Movable Armament.—The alternative positions selected for the movable armament must be connected by convenient communications; they must be supplied with suitable magazines, and with observing stations, from which the effect of their fire can be watched; and they must be secured against assault. Several methods have been suggested (see Chapter VI.), but it seems that the defence most readily provided on the scheme above set forth will be to take

* It is possible that in some cases the requisite invisibility may be obtained for heavier guns by the use of some form of disappearing mounting, but it is doubtful if this will, except under very special circumstances, enable the gun to remain long in action when attacked by high-angle fire.

advantage of the fire from the infantry redoubts, and to so place the artillery emplacements that this fire will cover their front, and to arrange such obstacles as will best detain the enemy under this fire. The guns themselves will also contribute largely to their own defence. According to the nature of the ground, therefore, the guns may be in batteries in front of, behind, or between the infantry redoubts, the last being probably the more usual position. These batteries would be similar in their interior organization to those used by the besieger, but their magazines and shelters should be more secure and their front better prepared. A simple plan, where the ground is suitable, is to place the guns behind the crest of a glacis-like slope, at the foot of which is a palisade or other obstacle covered from the enemy's fire. Sometimes a continuous parapet and glacis of considerable length may be constructed with a road behind it, from any part of which guns on travelling carriages can fire. If suitable mountings can be devised, a railway may take the place of the road.

Recapitulation.—We may now recapitulate the steps to be taken thus:—

1. Select the general position of the line of defences. This may be four miles or more from the place to be defended, but in special cases may be less.

2. Select posts to be held as main tactical pivots in the position. These, for their final defence, must depend on infantry fire.

3. Select main posts for artillery, both guns and howitzers or mortars, remembering the importance of invisibility and mobility. These posts must be, at least, sufficient to check the enemy at a distance and force him to bring up his siege train, and so give time to the defence to complete its preparations. In some cases they *may* coincide with the infantry pivots.

4. Select alternative posts for guns into which they can be moved as circumstances require.

5. Provide that all batteries shall be sufficiently covered by infantry fire and obstacles to be assault-proof. (What *is* practically assault-proof is a much debated question which will be reverted to hereafter).

Advantages of the Defence.—If a place is fortified on the principles above sketched, we see at once that, since the guns are all to be mobile, the defence loses one of its old advantages, viz., the power of employing much heavier guns than those of the besieger. What advantage can it still secure, in a well-prepared fortress, over the attack?

1. Although the *guns* must be mobile, it will still be possible to employ heavy howitzers or mortars, for which, as they are in well-concealed positions, mobility is less essential. Railway mountings may be devised which will again enable heavier guns to be used also.

2. Perfect knowledge of the ranges.

3. Perfect internal communications, including circular and radial railways.

4. Overhead cover is easily provided for the garrison.

5. Machine guns are exceptionally useful against large working parties and in resisting assaults. They are also available for a few sentries or picquets, and thus increase the security of the line of defence.

6. The magazine gun similarly increases the resisting power of sentries, etc.

7. The 3-pounder Q.F. gun is very effective against sapheads. At 500 yards its shell penetrated four feet of sandbags and destroyed the dummies behind, and its accuracy was such that it repeatedly struck the saphead.

8. Smokeless powder helps the best covered force and the most mobile armament, both of which advantages ought to be secured by the defence.

9. The fore and background may be prepared by planting. Belts of trees, 200 or 300 yards in rear, help to increase the invisibility of guns, etc., and to give cover for the movement of troops. They may also form second lines, to be held by the field force.

10. Obstacles can be prepared *ad libitum.* If trees are grown on the glacis, they may be utilized as abatis, and their roots will hinder sapping.

Strength of Garrison.—The steps indicated above (page 77) having been taken, we are now in a position to determine the approximate strength of the garrison and to design the works in detail. To a considerable extent these two points affect each other, and the nature of the works may also be greatly affected by the *quality* of the garrison. For rough calculations it may, however, be assumed that, generally, the redoubts will be held by half a battalion, say 400 men, and that the total garrison of the fortress should be about one man per yard of the perimeter on which the redoubts stand. Of course, these figures only give rough approximations, and the proper garrison must be calculated for each case on its own merits. (See L., pp. 56—62). The garrison of Paris numbered $3\frac{1}{2}$ men per yard of the perimeter in September, 1870, and later in the siege the total under arms was twice this number, but it must be remembered that a very large proportion were of very indifferent quality as soldiers. Metz was held by about 5½ men per yard, but would probably have made a better defence if, instead of 150,000 men, there had been only 40,000, which is the garrison allotted by the Germans, and which amounts to about 1½ per yard. At Strasburg, the French averaged ⅔ man per yard for the whole perimeter, but had 3½ per yard on the front attacked. At Plevna, in 1878, the Turks numbered less than one man per yard for the whole perimeter, and not more than three per yard were available on the front of 7½ miles which was attacked.

The principle on which the extensive positions now held by the defence must be occupied is the same as for investing forces, namely, that the main position must be well screened by outposts and held in such strength only as will enable the reserves, stationed at more or less central positions, to come in time to the threatened points. Good communications, telephonic and telegraphic, by road and by rail, must be provided throughout the position to enable concentration to be rapidly effected whenever and wherever required.

CHAPTER III.

The Armament of Land Forts and the Effect of Shells.

Before proceeding with designs for fortification, we must know what ordnance can be used in the defence, and what is the power of the shell fire to which our works will be exposed.

The number and nature of pieces to be mounted in any given place must, of course, depend on the character of the work to be done and the ranges required. The number may vary from two or three in a redoubt to 20, or even (as in some French forts) 50. As to the total number required for a fortress, no absolute rule can be laid down, but an approximate idea may be obtained by assuming that it shall be about double the proportion usually reckoned for an army in the field, which is three guns per 1,000 men. The garrison being roughly calculated at one man per yard of perimeter, we may then reckon the ordinary armament at 12 pieces per mile, not including machine guns. The calculations must, however, be made for each case, and very much must depend on the mode of mounting, as well as on the nature and strength of attack to be expected. Care must be taken to provide sufficient field guns, etc., for sorties; and it is probable that in future the tendency will be to increase the proportion of pieces for indirect fire, and to diminish that of those for direct fire. Major Clarke, R.E. (*Fortification: Its Achievements*), recommends three types for indirect fire, viz.:—(*a*), permanently-mounted 10 or 12-inch mortars; (*b*), the heaviest howitzer or mortar that can be *easily* moved; (*c*), a light Q.F. rifled mortar of about 4½ inches. There can be little doubt that some such types are required, although, possibly, howitzers may be adapted to serve the purposes of mortars, *i.e.*, to give high-angle fire at short ranges, and thus avoid the multiplication of types of service ordnance.*

* Practically, the only difference now between howitzers and mortars is the elevation at which they are used, pieces which cannot fire at greater angles than 35° being called howitzers. Thus the same piece might be a howitzer or a mortar, according to the way it is mounted.

General Brialmont considers that the besiegers *must* carry some form of movable overhead armour; that the besieged must, therefore, have guns from 17-c.m. to 21-c.m. (7 to 8-inch) to pierce it; and that the besieged also requires 12-c.m. (5-inch) pieces for use against siege works, and quick-firers against men. All these he would place in cupolas. In addition, he requires mortars behind, or on the flanks of, works, and quick-firers on field carriages. He, therefore, recommends the following general proportions for the main armament of a fort:—Two-fifths to be guns of 15-c.m., 12-c.m., 70-m.m. and 37-m.m. (say 6-inch, 5-inch, 12-pounder and 6-pounder); one-fifth to be howitzers, for high-angle fire at long ranges, of 21-c.m., 15-c.m. and 12-c.m. (say 8-inch, 6-inch and 5-inch); and two-fifths to be mortars, for high-angle fire at short ranges, of 21-c.m., 15-c.m., 12-c.m. and 9-c.m. (say 8-inch, 6-inch, 5-inch and 4-inch). For flanking ditches he requires 84-m.m., 70-m.m. and 57-m.m. (say 15-pounder, 12-pounder and 9-pounder), in such numbers as may be necessary; and for piercing the besieger's movable armour a few 17 to 21-c.m guns as above mentioned. In the intervals between the forts he puts howitzers and mortars, protected by armour, and Q.F. guns on travelling carriages with movable armour.

For British fortresses the armament must usually be selected from those pieces that have been officially adopted into the service, but some of the self-governing colonies order their own weapons from private firms, and, therefore, although generally following the lines on which the War Department is proceeding, they sometimes obtain weapons which have not been officially adopted. Lists of the service guns and mountings are published annually. Descriptions of them are to be found in the text-books of ordnance and carriages, and in the monthly lists of changes of war material; and also most of them are described, with such details as are required by R.E. officers, in Major Lewis' *Fortification for English Engineers.*

Guns for Land Fronts.

Guns on Travelling Carriages.—The guns *on travelling carriages* are of the following classes:—

Machine Guns (*a*), on field carriages, firing over a height of 3 to 4½ feet, according to pattern; (*b*), on the parapet carriage, firing over 4 feet 6 inches. The patterns in the land service (*Plate* I.), are the Gardner of two or five barrels, the Nordenfelt of three or five barrels (*Plate* I. and *Plate* II., *Figs.* 1 and 2), the improved Gatling and the Maxim. The five-barrel pattern will probably, for some time to come at least, be reserved for coast defence.

Field Guns.—Firing over about three feet. The height of the axis of the M.L. guns is three feet seven inches, and that of the B.L. 3 feet $3\frac{1}{2}$ inches. There are several old or experimental patterns which appear in lists of service guns, but those most likely to be used in future are the 12-pr. B L. (*Plate* II., *Fig.* 3), and the 20-pr. B.L. The latter is too heavy for ordinary field purposes, but will probably form part of the siege train, and might be used by the defence also. The R.M.L. 25, 16, 13, and 9-prs. (*Plate* II., *Fig.* 4, and *Plate* III., *Fig.* 1) would be available in many places, and could be used. A shield has been adopted "for use under exceptional circumstances." It is of toughened steel, ·125 inches thick, proof against the Martini-Henry bullet at 200 yards range, seven feet high by three feet six inches wide, and weighs $1\frac{1}{4}$cwt. The 12-pr. B.L. is considered the most suitable piece, except where a searching fire is required (and unquestionably superior to the 6-pr. Q.F. and machine guns) for the defence of intervals, and for the mutual defence of permanent works by one another, or by field works outside.

Q.F. Guns.—The only one on travelling carriage is the 3-pr. (*Plate* III., *Fig.* 2), which is intended for the movable armament of fortresses. The carriage is only adapted for moving on roads, not at a rapid rate, nor on rough ground. The height of the axis is 3 feet $5\frac{1}{2}$ inches, and the width of wheel track five feet. The Nordenfelt gives 15° elevation, the Hotchkiss 12°. They are useful up to about 1,500 yards range.

Siege Train Guns.—The guns of the present service siege trains are the 25-pr. (*Plate* III., *Fig.* 3), 40-pr., and 6·6-inch (*Plate* III., *Fig.* 4) R.M.L. The axis of the 25-pr. is at a height of 6 feet, and that of the 40-pr. 6 feet 6 inches, both the guns being supported on two lattice girders, which have two sets of trunnion holes, one for travelling and the other for firing. The 6·6-inch is an 100-pr., and has an hydro-pneumatic disappearing mounting on travelling carriage (*Plate* IX., *Fig.* 1). The height of its axis is 8 feet $5\frac{1}{2}$ inches. The 40-pr. R.B.L., on overbank carriage, with height of axis 6 feet $5\frac{1}{2}$ inches (*Plate* IV., *Fig.* 1), is also available.

All these guns will be replaced by B.L. guns for the siege train, but will long remain available for fortress defence. The corresponding B.L. guns are 4-inch (25-pr.) (*Plate* IV., *Fig.* 2), 5-inch

(50-pr.) (*Plate* IV., *Fig.* 3), and 6-inch (100-pr.). The two former are on lattice-girder overbank carriages, height of axis six feet six inches. The 4-inch B.L. will probably not be adopted for the siege train (its place being taken by the 20-pr. B.L.), and will, therefore, like the 40-pr. R.B.L., be available for the movable armament of fortresses. It can be fired satisfactorily from an ordinary railway truck, if mounted on a Vavasseur carriage * (*Plate* XIII., *Fig.* 2). There is an experimental H.P. mounting on travelling carriage, with which the height of the axis is 10 feet. The types of 6-inch gun and mounting are not yet decided.

Guns on Fixed Mountings.—The following fixed mountings are in use in our land fortifications at present :—

For Flanking Ditches.—32-*pounder S.B., B.L.* (*Plate* V., *Fig.* 1), on garrison carriage, for use in caponiers and flanking galleries of deep ditches. It fires over a sill 2 feet 4½ inches high, from a slide six feet seven inches long by two feet three inches wide, on A pivot racers of one foot six inches and six feet ten inches radii. Case shot only will be used. To avoid the need of traversing, it is intended to alter the muzzles to a bell-mouthed shape, which will allow the case shot to scatter over the whole width of the ditch. The racers can then be dispensed with. About 10 feet in rear of the gun is required for sponging.

Blocked-up 6-foot Parapet Carriages.—The 64-pounder R.M.L. is enabled to fire over parapets six feet high by being mounted on a "sliding, medium, 6-foot parapet" carriage on a traversing slide. There are several patterns of these carriages and slides, both iron and wood. One pattern of each is shown in *Plate* V., *Figs.* 2 and 3. *Plate* V., *Fig.* 2, is commonly called the "blocked-up" slide, as it consists of an old pattern slide blocked up to the required height by teak blocks bolted on below. The 80-pr. converted R.M.L., as well as the 64-pr., can be used on this mounting. There is also a similar mounting for 64-prs. for 5-foot 6-inch parapets.

Disappearing Mountings.—The counterweight or Moncrieff system is in use for 64-prs. and the 7-inch R.M.L. (*Plate* V., *Fig.* 4). On it the 64-prs. can fire over nine feet four inches, and the 7-inch over 11 feet, with 5° depression. All new disappearing mountings will be of the hydro-pneumatic type, but we have none of them on land fronts.

* At present Vavasseur carriages (except that shown in *Plate* XIII., *Fig.* 2) are for naval service only.

Howitzers and Mortars.

The service howitzers are the 6·3-inch, 6·6-inch, 8-inch of 46cwt., and 8-inch of 70cwt., all being R.M.L. (*Plate* VI.). They are mounted on travelling carriages, allowing fire up to 20° elevation or more, and, except the 8-inch of 70cwt., can also be fired from fixed beds.

Experiments are still proceeding with B.L. howitzers, but it is practically certain that the 6-inch B.L., on a travelling carriage, will be introduced as soon as the difficulty of securing a good anchorage for it is overcome. The 8-inch B.L. howitzer is too heavy for use on a travelling carriage.

Effects of Shells.

Effects of Shells.—We have next to consider the effects which the enemy's shell fire may produce upon our works, but unfortunately modern improvements in ordnance, in shells, and in ammunition are proceeding so rapidly, while at the same time exact data as to the results produced are so difficult to obtain, that it is far from easy to say what the power of modern siege artillery will be. Two points, however, stand out prominently—(1), high-angle fire is being greatly developed, and will enable batteries to be erected in concealed positions, which will deliver very searching fire; (2), shells of large capacity (four or five calibres in length) can be fired with extreme accuracy, and their effect is vastly superior to that of our present service projectiles. Much is heard of high explosive shells, and no doubt they will have their use, especially against masonry and armour, but many difficulties have still to be overcome before they can be considered altogether satisfactory. Moreover, it has still to be proved that they will be more effective against earthworks or troops than powder shells. The crater produced by the French 22-c.m. (about 4-inch) shell, containing 32 to 33 kilogrammes of melinite* in earth four mètres thick, had an area of four square yards. (The depth of crater is not stated). That made by the shell of the 6-inch B.L. howitzer is two feet to two feet six inches deep, and three or four yards in diameter. That produced by 4·5-calibre shell of the 8-inch B.L. howitzer is 18 feet × 18 feet × 5 feet, the burster being 37½lbs. of powder. A shell that was blind penetrated 28 feet, so

* The German 21-c.m. shell contains 22 kilogrammes of guncotton.

that if a good delay-action fuze is adopted very great effect may be expected from such shell.

Slopes of Earthwork.—Whatever the shells are, it is certain that wherever the direct fire of siege guns has to be resisted by earth slopes, these must not be steep. The limit of actual penetration does not ordinarily exceed about five feet, but nothing except a very gentle slope will finally resist continued fire. It is found that if shells strike the ground at an angle of 24° a great proportion of them ricochet, and that even up to 28° large numbers do so. Thus a slope of $\frac{1}{10}$ throws up most shells, and up to $\frac{1}{6}$ it is effective in throwing up large numbers.

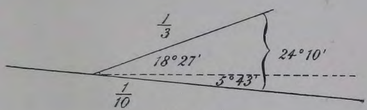

Fig. 1.

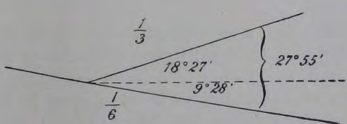

Fig. 2.

On the other hand, an excessive amount of earth covering has the effect of tamping the charge in any shell which penetrates a few feet before bursting, and thus increases the injury done to any concrete or other solid substance near which it explodes. On this account, the earth covering over masonry, etc., should not exceed four or five feet.

The best method of resisting modern shells, whether filled with powder or high explosives, seems to be by arranging alternate layers of earth and concrete. All casemates, passages, etc., of importance should also have an internal lining of iron or steel for all parts exposed to the enemy's fire, in order that, if the concrete is cracked, it may still be held up and not allowed to fall. The lining may be made of corrugated steel, or of steel or iron rails. The following section would appear to be efficient (L., p. 14) :—

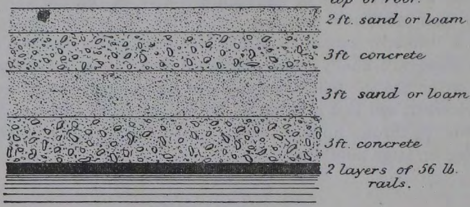

Fig. 3.

General Brialmont recommends from eight feet to nine feet six inches of concrete, disposed either in one mass or in two layers.

The penetration in feet of shells from siege guns firing direct into rubble is about equal to the calibre in inches. Into brick or concrete it is rather greater.

The penetration into wrought-iron armour plates of the 5-inch B.L. is seven inches at 1,000 yards, and five inches at 2,000 yards.

For other details see *Text-book of Gunnery*, and L., pp. 11—14. A useful summary of experiments at Lydd is given by Major Clarke in the *R.E. Professional Papers*, Vol. XV., 1891.

The following table shows some of the foreign siege trains:—

Table of Siege Trains.

	Austria.		France.		Germany.		Russia.		Spain.	
Guns.	9-c.m field ...	40	95-m.m. ...	9	... ...		4·2″ (10·7-c.m.)	80	... ...	
	12 ,, siege...	120	12-c.m. ...	30	12-c.m. ...	24	... ...		12-c.m. gun ...	24
	15 ,, ,, ...	60	15·5-c.m. long	20	15 ,, short...	12	6″ (15·3-c.m.) light	140	15 ,, ,, ...	18
	18 ,, ,, ...	80	15·5 ,, short	10	15 ,, belted	6	6″ ,, heavy	60	15 ,, howitzer	12
	... ...		22 ,, ...	4	... ...		... ...		21 ,, ,,	4
Mortars.	9 ,, ...	20	... ...		9 ,, ...	6	... ...		9 ,, ...	6
	15 ,, ...	40	15 ,, ...	6	15 ,, ...	6	6″ (15·3-c.m.) S.B.	40	15 ,, ...	4
	... ...		... ...		... ...		6″ ,, rifled	40	... ...	
	21 ,, ...	40	22 ,, ...	7	21 ,, ...	6	8″ (20·4-c.m.) ,,	40	21 ,, ...	4
	... ...		27 ,, ...	4	... ...		... ...		... ...	
Total pieces in unit ..	... ...	400	... ...	90	... ...	60	... ...	400	... ...	72
Percentage of mortars. ...	... ...	25	... ...	19	... ...	30	... ...	30	... ...	19

NOTE.—1 centimètre = ·3937 inch.
The common shell of the Russian 6-inch mortar weighs 60lbs., and has a burster of 10lbs.

CHAPTER IV.

Design of Individual Land Works.

The position to be occupied by a fort, redoubt, or battery having been selected, the successive steps to be followed in preparing the design may be enumerated as follows :—

Successive Steps in Design.—1. Determine the principal lines of fire required (rifle or artillery), and the number and nature of guns (if any) to be provided.

2. Determine the approximate length and position of faces and flanks ; in other words, the trace of the work. This necessarily involves a consideration of the garrison to be allotted.

3. Draw section lines from the crest, to enable the command and superior slope to be approximately determined.

4. Design the glacis (if any), and determine the exact commands.

5. Defilade the interior, and, if necessary, revise the results obtained under 3 and 4.

6. Arrange the interior organization.

Although it is convenient thus to classify the various steps to be followed, it is impossible to strictly separate them in practice. The last four are closely connected, and alterations made under any one head may affect the whole design. For instance, the alteration of floor level of a casemate or cartridge store may lead to fresh levels having to be adopted throughout the work, or a change in position or level of a gun emplacement, with the consequent changes in position or length of ramps, cartridge and shell stores, etc., may affect both trace and profile.

Lines of Fire; Number and Nature of Guns.—If the work is to contain no guns, it is only necessary to deal with the comparatively near ground and to arrange that it shall be thoroughly swept by rifle and machine-gun fire. It is impossible to lay down an absolute rule as to the distance within which no undefended space can be allowed. It is obviously desirable that there should be as little as possible, and all ground may be assumed to be defended over which the line of sight passes within three feet of the surface; but it would involve needless expenditure of time and money to level the whole within 800 or even 300 yards of the crest. When dealing with any piece of undefended ground, it is necessary to consider whether the enemy can reach it without very great exposure of himself, whether its area is sufficient to afford cover to any considerable number, and whether from it a dangerous attack on the work can be developed. It will then often appear that the place may be neglected; and, even if it is found necessary to defend it, it may be preferable to construct a special shelter trench or outlying work of some sort rather than level the ground or adapt the trace or profile of the main work with a view to this special area. As a rule, however, an attempt should be made to secure a zone of at least 300 yards width, within which there is no undefended space. In the intervals between any two redoubts, it must, of course, be impossible for the enemy to advance without coming under fire either of one of the redoubts or of intermediate defences.

If, although mainly for infantry fire, there are also to be some guns in the redoubt, the points on which it is most desirable that they should bear must be determined and the lines of fire laid down. Such points will be probable sites of siege batteries, main roads along which the enemy may advance, bridges which he must cross, favourable sites for siege parks, etc. Places which he can only reach in the intermediate stages of the attack may be neglected, as it is certain they will have to be dealt with by guns outside the redoubt. Flank defence for neighbouring forts may be considered, but, as already shown (page 74), it is seldom that guns for this purpose would be mounted in the infantry redoubts.

At this stage, however, the question arises, what guns must be mounted before war breaks out, and what may be safely left until it appears probable they will be required? It has been shown (page 75) that *some* guns must be ready at the very commencement to keep the enemy at a distance, and also to prevent a *coup-de-main*. Some of these guns may be mounted in separate batteries, but it may occur that the same place which is suitable for infantry occupation also affords good sites for guns to sweep the intervals, and for them or others to fire on the enemy at long range. It has already been shown that in such a case a few emplacements may be prepared in the redoubts for guns on travelling carriages. At the commencement of a siege the guns will be able to open fire without interfering with the infantry, and whenever desirable they can be removed to their alternative emplacements outside, while those they have vacated (not being cupolas or other complicated constructions) can be very readily adapted for use by the infantry. If, however, this policy is adopted, great care must be taken that the infantry requirements, for whose sake the redoubt exists, are not sacrificed to those of the guns, which are merely in the redoubt for temporary purposes. These emplacements should generally be at the salients, to enable a wide lateral range to be obtained.

Lastly, if the work is to be mainly or solely for artillery, the lines of fire must be carefully laid down and the work designed so as to obtain the utmost effect from each gun. The immediate foreground will only require such attention as to ensure that it is secured from assault by rifle fire either from the work itself, or more probably from the neighbouring redoubts, assisted by obstacles in front of the guns.

The principal lines of fire having been determined, wherever guns or howitzers are to be used, it is necessary to decide the number and nature of pieces to be mounted, which, as already pointed out, depends on the character of work to be done and the ranges required. The most suitable pieces must be selected from those detailed in Chapter III.

Trace and Profile.—The general lines of fire and the weapons to be used having been determined, the general trace of the work can be arranged. It must be such as will ensure that the immediate foreground is well swept by rifle fire, and that support can be rendered to the collateral works in the main line.

Deviation from Normal Admissible for Infantry and Artillery Fire.—In adapting the faces to the various lines of fire which are required, it must be remembered that infantry require some kind of head cover, which is usually provided either by giving a crenelated form to the crest, or by constructing sandbag or other loopholes. These devices limit the lateral range of each rifle, but, even without them, it is difficult to get men to fire in any direction which is not nearly at right angles to the crest. Thus, as a rule, it may be assumed that infantry fire can be reckoned on for a deviation of not more than 15° on either side of the normal. The deviation for artillery is only limited by the necessity of keeping the carriage on the platform, and of allowing the muzzle to overlap the interior crest by at least a foot, in order to avoid injury to the parapet by the blast. The ordinary double-decked platform (which is used for all guns on siege mountings) allows a deviation of $28\frac{1}{2}°$ on either side of the normal, but by adding small wings to the platform, thus :—

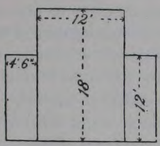

Fig. 4.

this may be increased to 45° on either side without the carriage leaving the platform. At a salient, almost any desired deviation may be obtained by further adding to the platform, provided only that the crest is so traced as to secure the necessary overlap of the muzzle, and that the platform admits of the wheels and trail recoiling four feet six inches without leaving it.

Where the faces required in order to give the desired lines of fire meet at an angle of 150° or more, there will be no ground, even on the capital, which is not swept by infantry fire. If the angle is less than 150°, one or more additional short faces must be introduced in order to avoid dead ground. Sometimes an emplacement for a machine gun might be suitably placed at such an angle.

Lengths of Faces.—The lengths of the faces are determined by the amount of fire to be developed from them. When occupied by infantry, it may be assumed that ordinarily the best result is obtained by allowing each man a space of five feet. This allows space for an effective loophole, for ammunition to be placed ready to hand, and for free movement. Each gun requires a width of not less than 15 feet for its platform, and may require more (see *Fig.* 4), but when there are several guns, the length of the face may be affected by the lengths of gun ramps, and by the number and size of traverses.

Artillery Ramps.—In order that the ramps may be as much under cover as possible, they should be kept nearly parallel to the crest. They should not have a greater slope than $\frac{1}{7}$, and are better if at from $\frac{1}{10}$ to $\frac{1}{12}$; and this, in conjunction with the command, decides their length.

Traverses.—There are many difficulties as regards traverses. They are useful for protecting a gun from being dismounted by oblique fire, for stopping shrapnel, and for confining the burst of a shell; but if they are to resist common shell, they must be of considerable thickness; if they are to screen the men from oblique shrapnel, they must be of great height; and even to protect a gun from being dismounted, they must (if the mountings are of the overbank, and not the disappearing, type) be decidedly higher than the crest of the face. On the other hand, if they are high, they mark the positions of the guns or men they are intended to protect, and they will sometimes catch and burst a shell which might otherwise be harmless. On the whole, it would seem that on faces chiefly exposed to direct fire the disadvantages of traverses (especially the conspicuous marks they afford) more than counterbalance their advantages, but on flanks, and also on front faces which are much exposed to oblique fire, it may be absolutely necessary to use them. When used, they should be solid, not less than 20 feet thick at top, and, when covering guns, sufficiently long and high to protect them from oblique fire. They should be 10 or 12 feet above the gun floor, but their height above the crest may sometimes be reduced (especially on flanks) by stepping the parapet down to a lower level beyond them. Their junction with the crest should always be rounded off so as to minimize their prominence. On the side exposed to artillery fire they should have as gentle a slope as practicable, and on the other should be revetted so as to give the maximum cover.

Distance Apart of Guns.—From a combination of the above considerations it will generally be found that, when guns are numerous, they should be about 100 feet apart on faces that are not enfiladable, and about 80 feet on flanks. In a modern fort, however, it is unlikely that the guns will often be numerous enough to render their spacing an important consideration, and in an ordinary redoubt they will, if used at all, probably be at the salients, where a wide sweep can be obtained. Thus, except in a battery, the length of face should generally be determined mainly, if not entirely, by the amount of rifle fire.

Garrison.—The garrison of a redoubt would usually furnish about 400 rifles, and the *total* length of crest may be roughly calculated by reckoning 1½ man per yard of *available musketry parapet* on main faces and one man per yard of gorge, so as to give a sufficient allowance for reserves, etc. It is, therefore, necessary to consider whether the spaces occupied by guns and traverses can be reckoned as "available musketry parapet." Sometimes the heavier guns would be replaced for rifle defence by machine guns, but where this is not the case, if the guns are on travelling carriages, it would be easy to adapt the parapet for rifle fire, when required, either by cutting out a step in the interior slope, or by arranging an improvised banquette of planks, etc. Along the front of traverses a narrow trench may be cut for occupation by rifles when required, without seriously reducing the cover afforded by the traverse. We must, further, consider in each case whether it is possible that all faces may have to be manned simultaneously. If not, a greater length of crest is, of course, admissible. Finally, a decision is needed as to whether more than one tier of fire is to be provided. As a rule, tiers of fire for simultaneous use are to be avoided, but this point will be further dealt with when we consider the profile.

The various points to be considered in calculating the entire garrison of a fortress are dealt with by Major Lewis (L., pp. 56—62), but it is necessary, as regards the detached works, to remember that he is mainly dealing with *forts*, not infantry redoubts.

Profile.—Having determined the approximate trace of the work, we can proceed to consider its general profile, and in order to obtain the necessary data for the adoption of a profile which will fulfil the requirements without undue extravagance, several sections of the natural ground must be drawn from the proposed site of the crest. It will then be possible to see what command and what superior slope will best ensure the thorough defence of the immediate foreground. Until these sections have been considered it will not be practicable to determine the *exact* position to be occupied by the work. The trace may be slightly varied, and may sometimes be moved considerable distances to the front or rear without materially affecting it, and only a comparison of the requirements on plan with those on section can lead to a final decision. Several trials will have to be made before it will be possible to determine for each face the section which most nearly meets all requirements, and which best harmonizes with those adopted for the neighbouring faces. It is quite unnecessary to adopt the same section for each face; and even on the same face the section may vary. The points to be remembered are that (*a*), ground is sufficiently defended if the line of sight from the crest passes within three feet of it; (*b*), that it is very undesirable, on account of the cost, that any large areas should be either cut away or filled up to a greater depth than 10 feet; (*c*), that as little cutting or filling as possible should be done, the natural surface being left untouched wherever possible; (*d*), that, in order to keep the work inconspicuous, the command should be kept as low as possible, say about 10 to 15 feet as a rule. It would be rarely possible to construct a work with satisfactory casemates and effective rifle defence with less command than 10 feet, and, on the other hand, 20 feet may be considered a maximum beyond which the command should never be raised without very urgent reasons.

Superior Slope.—It has been shown (page 85) that slopes not steeper than $\frac{1}{6}$ cause many shells to ricochet, while the majority will do so off a slope of $\frac{1}{10}$. The superior and exterior slopes of the main faces and flanks should, therefore, if possible, not be steeper than $\frac{1}{6}$, and whenever practicable, without unreasonable expense, they should be $\frac{1}{10}$ or flatter. On the gorge, where only attack by field guns is to be feared, steeper slopes may be used, as foreign field artillery now carries little or no common shell, and the bursting charge is in any case insignificant against earth. The superior and exterior slopes will often be identical, especially on the main faces, one slope being continued from the crest downwards, but if not, they must run gradually into one another, leaving no sharp intersection. Outside the exterior slope there must be an obstacle to check the enemy's assault. Formerly this obstacle was invariably a deep ditch, generally revetted with masonry, and always furnished with flank defence. It is now contended that such a ditch is unnecessary, and adds needlessly to the cost of fortifications.

Twydall Profile.—In its place, it is proposed to substitute what is now well known as the "Twydall profile,"* which consists of a continuous gentle slope from the crest to 15 or 20 feet below the original surface of the ground. At the foot of the slope a steel unclimbable palisade 9 feet 6 inches high is erected (*Plates* VII. and VIII.), and beyond it the profile is finished by a steep earth counterscarp covering the palisades from artillery fire. This is all the permanent obstacle provided, but wire entanglements, etc., would be freely used on the gentle slope, and also, if necessary, on the enemy's side of the counterscarp.

In some cases, the configuration of the ground would make the Twydall profile impossible, but where a choice between the two types is possible, the arguments may be briefly summarized as follows:—

Arguments for the Twydall Profile.—It is difficult to see at a distance, and very difficult to breach; it may be guarded by obstacles which

* See "Semi-permanent Infantry Redoubts," Vol. XI., *R.E. Professional Papers*, 1885.

cannot be easily destroyed ; it is cheap, and, therefore, enables more money to be spent on guns ; it is rapidly built, and, therefore, frequently obviates the necessity for heavy expenditure on works which may never be required ; it affords sufficient protection because the ultimate defence depends on infantry fire in any case, and this is provided in ample quantity by a series of Twydalls ; it does not require small bodies of men to be shut up in caponiers and galleries where they can know little of what is happening, and where they may be cut off if the enemy is successful.

Arguments against the Twydall Profile.—The efficiency of the obstacles is less than that of deep scarped ditches, and their destruction (like that of masonry revetments) is merely a question of the expenditure of ammunition ; also, the moral support afforded to the garrison by a deep ditch, which looks such a formidable obstacle, is much greater than that given by palisades, entanglements, etc. ; surprise would be easier ; a large force of good infantry is required, and, in fact, the defence depends on an army and a movable armament in field positions instead of on a much smaller garrison in strong, deliberately-built, heavily-armed works. Moreover, recent experiments have shown that the obstacles are not so difficult to destroy, nor the parapet to breach, as was supposed, especially when large capacity shells are used.

On both sides arguments deduced from war experience are put forward, but the general balance of opinion seems to incline more and more towards the adoption of the Twydall profile, modified to suit various conditions. To rightly assess the merits of the two arrangements, it is necessary to consider briefly the circumstances under which the works and obstacles are required.

So long as the enemy is at a distance, it does not matter whether the ditch is deep or shallow, whether it is flanked or not. The important points at that time are (*a*) that the guns should be protected from the enemy's fire as much as possible ; (*b*), that the works from which the infantry will ultimately have to deliver their fire should be as inconspicuous as possible, and well provided with shell-proof cover ; and (*c*) that the magazines shall be secure.

These points may be provided for by—

(*a*). Guns which can easily disappear either by moving from place to place, or by disappearing mountings.

(*b*). Works of low profile, with no sharply-defined slopes or angles, containing good casemates.

(*c*). Magazines well covered and not too concentrated.

When the enemy comes near, either after a prolonged period of siege operations, or by an attempt to carry the place as if it were a field position, or by surprise, the essential points are—

(*a*). That the infantry should not be liable to be overwhelmed by distant artillery or rifle fire before the assault is delivered.

(*b*). That it should be impossible to neglect the detached works and pass them by.

(*c*). That the guns should not be exposed to capture by small raiding parties.

(*d*). That the fire from any work or group of works assaulted should be ample for its own protection.

These points are provided for by—

(*a*). Good casemate accommodation *close* to the lines of parapet to be occupied by infantry.

(*b*). Works placed so near to one another that their fire sweeps all passable intervals, so that if any interval is forced, some of them must still be carried before the enemy's communications are in any way secure.

(*c*). Heavy obstacles or rifle fire in front of the guns. A good ditch may secure this. Hence General Schott proposes a ditch 20 mètres wide, full of abatis, etc., in front of all the batteries (Chapter VI.)! Some such solution is inevitable if the guns are to be movable, and if their protection is to be ensured by obstacles *alone*. It would seem better to have a moderate use of obstacles in the most exposed places, and good rifle fire, which may best be delivered from a redoubt acting as a keep, or rather guard, for a group of several gun emplacements.

(*d*). The final point is that on which the Twydall profile *v.* deep ditch controversy largely turns. We may take it for granted that no enemy can assault, with prospect of success, a work held by good unshaken infantry. Therefore, frontal defence of the ditch is sufficient if the infantry to hold it can be preserved unshaken to the last.

Similarly, no enemy can hope to cross a well-flanked ditch until the flanking defence is ruined.

Which is easier, to preserve the infantry for front defence (*i.e.*, for main parapet) unshaken, or to preserve the flanking galleries or caponiers, with their garrisons, intact and unshaken? For the former, good casemates to give protection from distant fire, easy access from them to the parapet, good head cover on the parapet, and either a wide, clear foreground, or an obstacle which will detain the enemy under the frontal fire, are required. All these are easily and well provided by the Twydall profile, and all, except the last, are required in any case.

To preserve the flanking galleries, it is necessary that the enemy should be unable to occupy any places from which he can breach them either by direct or indirect fire, or by mines—a somewhat difficult condition to ensure. Nevertheless, when this *can* be ensured they may be useful adjuncts to defence, and must not, therefore, be condemned as altogether obsolete. But there is this further consideration, that whether they exist or not, no enemy can assault until he has thoroughly shaken the frontal defence. When he has done this, he will not usually have much difficulty in ruining the flanking galleries, even if their defenders remain unaffected by the knowledge that the main garrison is so shaken as to be unable to repel the attack, and that if they (the flankers) fail to do so, they will be cut off in their galleries.

In both cases the obstacle in front of the parapet must be to some extent destroyed before an assault can take place, and there is no doubt that both masonry revetments and the combination of steel palisades and wire entanglements can be destroyed by a sufficient expenditure of ammunition, especially when large capacity shells are used; but experiments are still insufficient to compare the relative amounts required to effect and maintain a practicable breach through them.

The obstacle afforded by the Twydall profile may undoubtedly be increased by the adoption of a high masonry counterscarp, as this gives better cover to the palisade and entanglements, and makes the descent into the ditch more difficult for an assaulting party.

Details of Deep Ditch.—If a deep ditch is used, it should be from 20 to 30 feet deep, and should be so narrow that shells passing over the crest of the glacis at $\frac{1}{3}$ should not strike the masonry escarp. The escarp should not be less than 15 feet high; the counterscarp should be higher. If the soil is chalk, the revetments need be scarcely more than mere facings to prevent weathering. In other cases they may be built according to Pasley's and other rules (L., pp. 101—104). A concrete or masonry slope at the foot of the escarp and counterscarp makes the descent into, and ascent from, the ditch more difficult. The top of the counterscarp should be rounded or given a smooth slope. Both escarp and counterscarp revetments should be built in cement.

Flank Defence of Ditch.—Flank defence should be given to deep ditches by caponiers, or escarp or counterscarp galleries (L., pp. 108—110). The last-named are generally the best, because they flank the ditch without leaving any undefended space, they are not liable to be breached from a distance, and they give facilities for countermining. On the other hand, communication with them is difficult.

Glacis.—Having decided whether to use a deep ditch or not, the arrangement of the glacis has to be considered, and in doing so the first object should be to have *as little movement of earth as possible.* The methods of constructing a glacis are dealt with in Capt. Cleeve's notes on "The Application of Works to Irregular Ground" in Vol. XVIII. of the *R.E. Professional Papers* (1892), and need not be further enlarged on here. The data to remember in making the design are that ground within three feet of the line of sight is sufficiently defended, that the natural surface should be left untouched wherever possible, that no cutting or filling should, if possible, exceed a depth of 10 feet, and that the glacis must necessarily be at a gentler slope than the superior slope, if it is to be swept by fire from the crest.

Covered-way.—Sometimes, however, a *covered-way* may be provided, in which case it may sometimes not be necessary for the glacis to be seen from the crest.

The object of the covered-way may be (*a*) for the main infantry fire, in order to sweep steep ground which cannot be seen from the crest; (*b*), for a second tier of infantry fire; (*c*), for guns, the infantry fire being from the crest. Cases (*a*) and (*c*) can only occur when, for some reason, it is necessary to occupy very nearly the same site with both artillery and infantry. For instance, a commanding spur occupies a prominent position in the general line of defence, and to ensure the due defence of its forward slopes in the close attack, a line of rifle fire must be established some little way below the summit. At the same time, its summit offers an excellent position for guns to meet the enemy's artillery attack. The case (*a*) may then arise, the rifle fire being furnished from forward trenches, and the guns being mounted behind in a battery. It may then probably be found convenient to form these trenches and battery into one work, which will consist of a fort with covered-way. In this case the design of the glacis is not affected by the superior slope, as it is only intended to be defended from the covered-way.

Case (*c*) may, in special cases, be a convenient way of securing protection for the guns, and it enables them to be moved without interference with the regular defence of the fort, but it has the disadvantage of marking their position more prominently than if they were clear away from it, while, on the other hand, they lose the command given by the high parapet above them. This is, however, not often a matter of so much importance to the guns as it is to the rifles. Both cases (*a*) and (*c*) have the disadvantage of offering a deeper target to the besieger.

Case (*b*) will not often occur. Two tiers of fire are seldom desirable. If the men are available, they will generally be more usefully employed in extending the front than in giving a second tier.

Thus the construction of a covered-way will always be an exceptional case, and it must be remembered that it is inseparable from certain difficulties as to its defence. If it is held by a part of the garrison of the fort, communications by which they can retire to the interior of the work are difficult to arrange in such a manner that they can be used in face of a victorious enemy. Therefore, there is risk of either allowing the defenders of the covered-way to be cut off or withdrawing them prematurely. If the covered-way is held by a part of the field force, the commandant of the fort is in the unpleasant predicament of knowing that his outer line of defence is held by troops over whom he has no control.

CHAPTER V.

INTERIOR ORGANIZATION OF LAND WORKS.

THUS far we have only dealt with the work from crest line outwards. Now we must consider the interior. It is essential that certain parts (for instance, the main communications) behind the crest should be defiladed from the besieger's view and as much as possible from his fire.

Defilade.—If possible, the whole interior should be screened from his view, and this is what is generally understood by "defilading" the work. In modern works, however, where there are no large parade grounds, and where nearly the whole interior space is occupied by the necessary lines of communication and large traverses or parados covering casemates, the defilade from view may generally be neglected because it is much more than provided for by the defilade from fire.

From View.—If, however, there is any interior space to be defiladed from view, all that is necessary is to ascertain which of those points which the enemy might occupy are the most commanding (these are, of course, not necessarily the highest summits). Scales may then be drawn of the planes passing through those points and the crest line, and by inspection of these it is possible to see at once whether the required defilade is secured in the interior. If it is not, either the crest must be raised (which involves a rearrangement of all the exterior work), or the interior must be excavated, or additional traverses or parados must be provided.

From Fire.—Wherever protection from fire is to be given, it must be ensured either by overhead cover—the *only* means of meeting high-angle fire—or by taking care that projectiles passing over the crest at a slope of $\frac{1}{3}$ will pass above the point where protection is required. Thus any road should be *at least* six feet, and preferably seven feet, below fire falling at $\frac{1}{3}$, if it is one which would have to be used during action, while all masonry exposed to the enemy's fire is sufficiently covered from direct fire if the $\frac{1}{3}$ line passes clear above it.

The slope of $\frac{1}{3}$ is taken because the great majority of shrapnel balls do not fall at a steeper angle, and the angle of descent of other projectiles from siege guns is less than this. In fact, a slighter slope might be taken in considering the protection given to masonry, except that it is desirable to leave a decided margin of safety to allow for the inevitable injury to, and consequent lowering of, the protecting crest, and also for the possible effect of large capacity or high explosive shells bursting near the top of the masonry.

Interior Slopes should be revetted as much as practicable in order to gain cover for men behind them. Sometimes a masonry revetment may be desirable, but usually an earth slope about $\frac{1}{1}$ may be left, which can be cut off and revetted when required.

Masonry should always be well below the enemy's line of fire, and, therefore, revetments and retaining walls will often have to be finished at top with a short earth slope.

The *banquette* should be five feet wide from the interior crest, to allow of machine guns on parapet carriages being used. The slope of the banquette, if very short, may be $\frac{1}{1}$, but is usually $\frac{1}{2}$. If it is longer than seven feet, there should be an intermediate level introduced to break it, or the slope should be reduced.

Steps may often be substituted for slopes. They may be of concrete, but if they are likely to be struck by projectiles, should be merely cut out in the ground and revetted with planks.

Parade Grounds are not required.

Gun Terrepleins should not be wider than absolutely necessary for the working of the guns, allowing sufficient space for moving them away conveniently when required. This would usually mean about 25 feet from the interior crest, *i.e.*, space for the double-decked platform, and five feet in rear of it.

Loopholes.—L., pp. 90—92.

Gates and Keys.—L., pp. 106—108.

Drawbridges.—L., pp. 110—121. A new form of drawbridge, invented by Captain Bate, R.E., is being tried, and may be introduced.

Accommodation Required.—The various classes of accommodation which have to be considered in connection with forts will now be mentioned. Probably no single fort will ever contain all, but in preparing a series of designs for the complete defence of a fortress, it might be necessary to consider every one of the details here mentioned. It is not intended to give such detailed descriptions as would enable an officer to prepare and execute working drawings, but merely to give such general information as will enable him to understand and prepare general designs, and will also show where to obtain further details.

For the benefit of the junior officers who have not yet been employed on works, it may be mentioned that the *List of Changes of War Material*, which is published every month with Army Orders, and the I.G.F.'s circulars, which are published from time to time as required, must always be consulted by any officer engaged on fortifications.

Ordnance.—The nature of the pieces available for land works has already been dealt with (pp. 81—84). In any work where provision is to be made for their use, it is necessary to consider their emplacements, platforms, anchorages, and ramps. Even in works where they are not to be mounted, it may be necessary to provide for their storage, and for the observation of the fire from neighbouring batteries. The storage of ammunition is also exceedingly important, and may have to be provided for even in works which do not themselves mount any guns.

Emplacements.—These may be on the main parapet or in the covered way, or in an interior battery. At one time this third alternative was looked on with much favour, but it has the serious defect of increasing the depth of the target for the enemy's projectiles, and would probably be seldom employed now. The second alternative is open to the same objection, but would generally lend itself more easily to complete mobility of the guns. As already explained (p. 98), however, it would only be adopted in exceptional cases. In all ordinary cases, wherever guns are mounted, whether in forts, redoubts, or batteries, they will be on the main parapet.

All pieces on travelling carriages will be fired from the ordinary "double-decked platform" used in siege batteries, but in many cases this will be enlarged by wings to allow the gun to be trained through a greater angle (p. 91). The platform being of wood, and of regulation size (18 feet by 15 feet), is kept in store until required, but the wings, being of variable size to suit the local requirements, are made of concrete. Where much training has to be given, it may be necessary to give a circular form to a part of the front parapet to prevent the wheels colliding with it. For M.L. guns the platforms should be laid level, but for B.L. guns a slope of $\frac{1}{24}$ to the front should be given to facilitate their running up.

The emplacement for any gun should allow space for the platform and for free passage (say five feet wide) behind it.

Anchorages.—The anchorage for the 6·6-inch gun is shown in *Plate* IX., *Figs.* 1 and 2. The only other anchorage yet adopted into the service is the "radial" C pivot for double-decked plat forms (*Plate* IX., *Fig.* 3). The official name is "Platform, siege, double-decked, C pivot, Mark I." It is provided with a radial arm for attachment to an upward buffer on the 4-inch and 5-inch B.L. guns (*Plate* IV.), and with a pivot-plug, to be used instead of the arm, for attachment to an horizontal buffer on the R.M.L. howitzers (*Plate* VI.). For the B.L. howitzers no satisfactory anchorage has yet been devised, for it is important not only that it should securely anchor the howitzer without disturbing the platform, but also that it should not require excessive time or labour for laying.

For other guns of siege type there is no anchorage, but inclined planes of wood are placed for the wheels to run up on.

Ramps for guns should be from $\frac{1}{10}$ to $\frac{1}{12}$, except for very short distances, when they may be as steep as $\frac{1}{7}$.

Gun Shelters.—Shelters might be useful for guns to be withdrawn into when not required, *e.g.*, guns for use on flanks when there is no immediate prospect of their being wanted, or machine guns when no infantry attack is yet threatened. If a shelter is intended to be for any particular gun, care must be taken to allow sufficient space for the kind of carriage to be used with it. Whether special gun shelters are provided or not, it is necessary to remember not only the guns of the fort, but also those of the movable armament, and to provide for their storage. Where (as in old forts) there is plenty of interior space, sheds may be built for them wherever convenient, as the guns will all be taken out long before the fort comes under fire. Where (as in new forts and redoubts) space is very limited, care must be taken that sufficient storage room is provided either in casemates, which in war may be utilized for other stores or for the garrison, or in covered passages of sufficient width to receive the guns without so blocking the communication as to hinder such work as is necessary in peace.

In gun and carriage sheds it is sometimes convenient to lay down wheel guides. These should give five feet six inches wheel track in order to allow for variations in width, which are found to occur frequently in old carriages as the result of local repairs, etc.

Observing Stations.—It is essential that the effect of the fire of all guns should be observed as far as possible, and, therefore, wherever guns are mounted, observing stations are required. These need not necessarily be actually beside the guns, and where high-angle fire is used they may have to be at some little distance, but the distance should seldom be great, or the difficulty of identifying the fire of any particular gun, or even battery, may be excessive. In some cases the observing stations for intermediate batteries may be in the neighbouring infantry redoubts. When practicable, they should be given bullet-proof protection, and in some cases might take the form of lightly-armoured conning towers.

Storage of Ammunition (L., Chapter III., to which constant reference must be made for all questions of dimensions and other details not dealt with below).—Magazines for the storage of large quantities of powder in bulk will be rare, but every fortress will need cartridge and shell stores for its detached forts or batteries and for its movable armament, and also small-arm and quick-firing ammunition stores. These stores should not be too concentrated, and it may be found advisable to construct the main stores (or at least those for cartridges) apart from the batteries, in situations where complete security may more easily be given to them. The main stores should provide for about 60 rounds per gun per day for the time it is expected the fortress should hold out without relief. In the forts and batteries it will usually be sufficient to provide accommodation for 200 rounds per gun in stores as close as practicable to the guns. The cartridges for all guns smaller than 7-inch R.M.L. and 6-inch B.L. are packed in metal-lined cases measuring 17 inches × 17 inches × $20\frac{1}{2}$ inches, which are not allowed to be stacked to a greater height than 11 feet. If possible, each gun should have its own shell and cartridge store, and in no case should the ammunition for pieces of different natures be placed in the same store. In or close to the gun emplacement recesses should be provided, where a few rounds may be stored which are intended for use in emergency. Under ordinary circumstances, the gun should be supplied direct from the shell and cartridge stores, the ammunition in the recesses being used only if at any time the ordinary supply is not rapid enough.

Q.F. and small-arm ammunition stores must be separate from those for other guns, as their cartridges contain their own means of ignition. Q.F. stores should provide for about 2,000 rounds per gun. A convenient size for the store for one 6-pounder Q.F. is 10 feet × 8 feet × 8 feet. The cartridge box for the 4·7-inch Q.F. gun contains six rounds. Its dimensions over all are: length, 25·25 inches; width, 17·75 inches; and depth, 20·24 inches. Small-arm ammunition is packed at home and for active service in boxes measuring $22\frac{3}{16}$ inches × $8\frac{1}{2}$ inches × $7\frac{9}{16}$ inches deep, and containing 1,100 rounds. The box for general service is of slightly smaller dimensions, and better made.

If high explosives are used, separate magazines for them will become necessary.

Shot and Palliser shell may be stored in the open, but all other ammunition must be *well* covered, and it is best that at least the cartridge stores should be well sunk in the solid ground, as it becomes increasingly difficult to provide built-up cover which will long resist modern shells. Every store where powder is kept, whether in bulk or in cartridges, must be entered through a *shifting lobby*, where magazine clothing is put on. On the inner side of the shifting lobby everything must be under "magazine conditions." Issuing hatches should be provided for the issue of ammunition, and not doors, if the men receiving it are not under magazine conditions. When there are lifts to carry the ammunition to the gun this will not be the case, as the entire communication from the store to the bottom of the lift should be under magazine conditions. For the reception of ammunition into the store, a hatch or door may be provided, which should be kept locked except when ammunition is actually being received. In some small stores, instead of a shifting lobby, merely a barrier is provided, the men on the inner side being under magazine conditions.

Lamp Passages must be provided for all stores, etc., which are under magazine conditions, wherever these cannot be lighted from the outside. If possible, access to them should be obtained direct, without passing through other stores or casemates. Usually, they are on the same level as the stores they light, and the lamp recesses are then merely rectangular openings in which the lamps are placed, covered by strong plain glass and wire guard on the store side, and by a locked door on the passage side. Sometimes, where the ground area is limited, the lamp passage is overhead, and the lamps are inserted in the roof very much as in railway carriages.

Lifts will seldom be necessary in redoubts, and may often be dispensed with in any work that has no guns too heavy for travelling carriages.

Laboratories and Shell-filling Rooms.—Formerly, separate cartridge and shell-filling rooms were considered necessary, but it has now been decided that the *same* room may be utilized for either purpose *at different times*. In future, therefore, *laboratories* (*Plate* X., *Figs.* 1 and 2) will be provided instead. These will not be required in each fort, but one or more will be provided for each station according to local requirements. The inner room will be for filling operations. Both rooms must be under magazine conditions. At large depôts a separate building (*Plate* X., *Figs.* 3 and 4) will be provided for shell emptying, but at small stations where this is not needed shells can be emptied (under proper supervision) in the outer room of the laboratory.

Artillery Stores.—The responsible artillery officers should always be consulted, if possible, when these are being designed. In action, most of the stores will either be in use, or will, at least, be placed as handy as possible to the guns for use when needed, and, therefore, the buildings need not necessarily be bomb-proof. It will, however, be frequently the simplest arrangement in modern works to construct a series of brick or concrete buildings under a parados or elsewhere which will be available for these and other purposes. An artillery small store, an artillery general store, and a smiths' shop are needed (L., pp, 288—292). Side-arms must be provided for, but these are generally stored on racks in the centre of the artillery store, or on hooks against a wall.

Casemates and Shelters for Men (L., pp. 95—99).—Sufficient shelter for the full war garrison must be provided, but it must be calculated, not on ordinary barrack rules, but on those applicable to service in the field. Thus, if a space six feet by two feet for each man, and a 3-foot passage between rows of beds is allowed, there will be space enough. If accommodation for the war garrison is provided at this rate, there will be ample room for the small peace garrison without any infringement of the ordinary rules applicable to barrack occupation. In considering the war accommodation, account may often be taken of any wide underground galleries, etc., as these would often furnish excellent shelter.

It is important that access to the parapet should be as easily obtained as possible from all the casemates, and that although some (perhaps the majority) may be under a parados, some at least should be under the front parapet, so that their occupants may be able to reach the banquette at the shortest possible notice. Some of the casemates may be fitted as ordinary barrack rooms for peace purposes, but all that are not intended to be occupied except in war will merely require doors, windows, and fireplaces. These should not be omitted—as they have been in many cases—as their absence might seriously affect the health of the war garrison, and there will, in any case, be so much to do on the outbreak of war that such matters would then, very probably, be neglected.

The living-rooms should all be as bombproof as possible, the cover over them being sufficient to resist the heaviest shells thrown by siege ordnance. If they were built on the ground-level this might necessitate very excessive command being given to the whole work, and, therefore, their floors must generally be sunk to some extent below the surface; but it may be desirable to reduce the protection given to a few of them in order to make it more practicable to utilize them as comfortable barrack rooms in time of peace. Very frequently, however, a fort will require no peace garrison stronger than an ordinary guard.

General Brialmont states that the fumes produced by melinite shells are so suffocating that special precautions must be adopted to obviate danger from this source. He, therefore, recommends that exterior doors should never open into living rooms, but into passages. In this case windows also would require special protection. The point need not be pressed too far, but it deserves to be borne in mind when designing casemates.

Other Stores.—If there is a peace garrison, some of the war casemates will furnish ample room for all its necessary stores. During war, the garrison will be supplied as an army in the field, from main stores in the fortress. Therefore, many, perhaps all, of the detached forts would require no further storage space, except one provision store; but when preparing complete designs for an entire fortress, it is necessary to remember that provision must be made somewhere for all the mass of food and other stores which will be poured into the place whenever it is being prepared to stand a siege (L., p. 98).

Latrines must be provided (L., p. 96).

Tanks, Reservoirs, or Wells must be provided (L., p. 98). Great care must be taken to ensure a *secure* water supply.

Electric Light Emplacement.—Any important fort should be able to obtain the assistance of a search light. This would not necessarily mean the provision of a light in each work, but it must be remembered that these lights cannot be relied on beyond 2,000 yards. At present each light requires its own engine-room, but it is possible that a method may be contrived of driving several lights from one central station.

Communications must be good and secure (L., pp. 99—101). In addition to the road and passage communications, those for the transmission of news and orders must also receive careful attention. Telephones, telegraphs, and speaking tubes will all play an important part in the general defence of a fortress, and every fort should contain at least one room where the necessary apparatus can be fitted up. This must be in a secure position, and as near as possible to the post most likely to be occupied by the commandant of the garrison.

Railways.—The utilization of railways for the defence of a fortress deserves, and will no doubt receive, constantly-increasing attention. Their use will be for two distinct purposes: (*a*), the movement of guns on the fighting perimeter; (*b*), the conveyance of ammunition and stores of all sorts from the central magazines and depôts to the forts and troops engaged.

A system which indicates the manner in which this branch of the defence will probably develop is mentioned in Chapter VI., pp. 110 and 112, but further discussion of the details would be out of place here.

CHAPTER VI.

Foreign Proposals.

It is not possible, in a single chapter, to describe with much detail the various systems of fortifications which have been suggested of late years, but a slight sketch of some of their more salient features will not only be of interest to those who have not studied them, but will also, perhaps, suggest ideas which may be utilized even by those who cannot adopt the schemes in their entirety.

Major Clarke (C., Chapter VIII.) gives general plans, etc., of some of the systems mentioned below.

General Brialmont (Belgian Engineers), whose opinion has very great influence on the Continent, and in accordance with whose designs Bucharest and the line of the Meuse have been lately fortified, proposes forts at a distance of from 3,000 to 8,000 mètres from the place defended, according to its importance, with intervals of from 4,000 to 5,000 mètres. The forts are very massive structures of concrete and armour, with deep, well-flanked ditches. Each fort is self-dependent, not looking for any flanking support from its neighbour's fire. Its garrison consists of artillery, and one or two companies (Continental) of infantry, say, two to four British companies. The field force of the garrison is also expected to assist in repelling any assault or attempt to penetrate the intervals. Round his chief forts, against which a regular attack might be expected, he requires a clear field of fire of 1,500 mètres.

The armament of such a fort he fixes at one cupola for two 15-c.m. guns, four for one 12-c.m. gun, three for one 21-c.m. mortar, four disappearing cupolas for two Q.F. guns, with sometimes the addition of two disappearing cupolas for one 12-c.m. gun.

In the intervals, he places howitzers and mortars in cupolas, and Q.F. guns on travelling armoured carriages. He also has an enceinte which, if the fortress is of a purely military character, is to be so armed and designed as to render a regular siege necessary even after the forts have fallen ; but if the fortress includes a large town which might be bombarded, and so forced to surrender, he considers it will be sufficient for the enceinte to be capable of resisting a *coup-de-main* delivered by troops who have penetrated the intervals, or who have captured two or three forts.

General Brialmont's latest ideas are developed in his two books *L'influence du tir Plongeant et des Obus Torpilles*, and *Les Régions Fortifiées.*

M. Mougin (Director of the St. Chamond firm) proposes batteries, each consisting of a mass of concrete buried in the ground, and carrying on the top three cupolas, each for two 15-c.m. guns, and four disappearing cupolas, each for two machine or Q.F. guns. Electric lights, observing stations, etc., are included in the same mass, and the whole is garrisoned by 30 or 40 mechanics. The intervals (about 3,000 to 4,000 mètres) between the batteries are occupied by a glacis parapet, behind which is laid a line of railway, off which guns on special travelling disappearing mountings fire. A second line of railway—for transport only—runs more or less parallel to the former, with radial communications wherever needed, to the interior of the fortress, and with connections at intervals to the firing railway. The transport railway is to be laid in time of peace, and can take the best advantage of the contours of the ground. The firing railway (which it is assumed will be required for an arc of about 10,000 mètres in a large fortress) is only to be laid along the front attacked. About 400 to 500 guns are allotted as the movable armament for a first-class fortress. The batteries are expected to delay the enemy sufficiently to give time to lay the firing railway and mount the guns on it. They are, therefore, designed so as to flank the glacis.

The railway system of M. Mougin meets with approval from General Brialmont for special cases, and it appears to have merits which might make it very serviceable when the ground is favourable, but his fort is ridiculed in very similar terms by two such opposite critics as General Brialmont and Major Clarke. The latter speaks of this "preposterous artificial mountain," and the former says that "it is certainly a mistake to think that a fort can consist of a mere artificial rock, without ditch, without ramparts, without interior space, without infantry to take part in the defence, and from which emerge cupolas that are worked by artillerymen and mechanics in the hollows of the rock !"

General von Sauer (Bavarian Artillery) recommends two lines of small cupolas say two guns each, placed chequerwise, at distances apart of from 1,000 to 1,200 mètres in each line, so that the actual interval would be only 500 to 600 mètres. Behind these intervals he would place the movable armament. He also advocates the provision in time of peace of all the stores necessary for improvising a fortress at the time and place where it may be needed, and storing them meanwhile at great railway centres.

General Schott proposes a line of semi-circular batteries 700 mètres apart, each battery to contain six disappearing cupolas armed with machine guns. The intervals are covered by a glacis, behind which he places the artillery (50 to 60 guns). The glacis is flanked by fire from caponiers in the gorges of the batteries. In front of all he excavates a ditch 20 mètres wide, and fills it with abatis, while on the glacis he places wire entanglements. These works would not necessarily be continuous, but would be constructed where needed, two batteries, with the glacis between, forming one complete unit. In fact, instead of "detached forts," he has "detached glacis" protected by machine-gun batteries on the flanks and heavy obstacles in front.

Lieut.-Colonel Voorduin (Dutch Engineers) proposes batteries at two kilomètres interval. Each battery has a cupola with two guns for fire to the front, and a caponier in rear of it, with iron shields, containing three guns on each face to flank the intervals, the whole being embedded in a mass of concrete, with an earth parapet in front, and surrounded by a wet ditch.

Lieut.-Colonel Schumann (Prussian Engineers)—now deceased—proposed disappearing cupolas, each for one 12-c.m. gun, with two 12-c.m. mortars behind it. In front of this cupola he places on the arc of a circle six other disappearing cupolas, each containing one 53-m.m. Q.F. gun. In the immediate front of the first cupola he places abatis, and in front of the Q.F. cupolas he has a glacis parapet and another much wider belt of abatis. From the first cupola two wings radiate to an extreme distance of about 500 yards on either flank, on each of which is mounted a battery of six 37-m.m. Q.F. guns on travelling armoured mountings. About 450 yards to the front of the main cupola is another battery of seven similarly mounted 37-m.m. Q.F. guns.

Colonel Laurent (French Engineers) proposes a line of batteries at three kilomètres interval, either without cupolas or with only one cupola in each, a casemate caponier in the gorge for flanking the intervals, and a line of guns behind the intervals. This system has a similar appearance at first sight to that of Voorduin, but the latter uses his forts to give direct fire to the front, whereas Laurent prefers that his batteries should merely flank the intervals, all his direct fire coming from the artillery behind those intervals.

Lieut.-Colonel Grainiciano (Roumanian Engineers) proposes a system attempting to combine the main points of several of those above mentioned. He places forts at 3,000 mètres interval, containing from three to five cupolas for two guns each, and caponiers in the gorge with two Q.F. guns for defence of the intervals. For their further defence he places in the middle of each interval a caponier with two or three Q.F. guns on each side, covered by a ravelin (or *ravelin caponnière* as he calls it), in order that there may be no possibility of this defence of the intervals being destroyed by distant fire. On the parapet of the ravelin he has two or three disappearing cupolas for Q.F. guns. He places the bulk of his armament on a railway according to M. Mougin's system. As regards the profile of his batteries, he says "the existence of ditches is only admissible when combined with escarps and caponiers which are indestructible from a distance, and perfectly secure against assault. If these conditions are not attainable, the glacis-parapet organization is justified by the perfection of fire-arms and the employment of suitable accessory defences."

There is a small infantry garrison in his forts and *ravelins caponnières.* The movable armament consists of about 112 guns and 56 howitzers, all working on the firing railway, and 112 mortars in batteries either in front or rear of the transport railway, the mortars having travelling carriages adapted for movement along the rails, but not for firing from them.

Lieut.-Colonel Grainiciano considers one armoured gun as equivalent to three unarmoured.

Summary.—We see from the above that whereas General Brialmont and M. Mougin put their forts or batteries at 3,000 to 4,000 mètres interval, and make each independent of its neighbour, the other officers desire to suppress the large forts altogether, and replace them by cupolas or small batteries with short intervals, the various works giving mutual defence to one another. All alike make liberal use of concrete and armour, but all, except General Brialmont, appear in reality to rely mainly upon their mobile artillery in the intervals for their main defence, treating their batteries, to a great extent, as arge caponiers to flank the intervals. It is true they vary in the degree to which they do this, von Sauer sowing the country broadcast with his little cupolas, Mougin giving his batteries a heavy armament, and only Laurent going to the extreme of not allowing his guns to fire direct to the front at all, and absolutely confining them to the caponier *rôle*.

As regards intervals between forts actually constructed, some details have already been given (Chapter II.), and it may be added that in French forts the armament is usually from 10 to 20 guns, but occasionally even 50, the garrison varying from 400 to 1,000 men. The armament of a German fort is usually from 8 to 20 guns.

In the summary of Continental opinion, compiled by Major Wolfe Murray, R.A., and published in the *R.E. Journal* of May, 1891, the following are the chief points affecting fortress defence, from which it will be seen that, in his opinion, Continental views are more and more tending to the abolition of large forts or fixed batteries :—

It is probable that in future the main works of a defensive position will take the form of strong infantry redoubts of low profile, with good bomb-proof cover for garrisons in close proximity to their posts, with, perhaps, a few field and machine guns. The probable garrison for these redoubts will be two to three companies of Continental strength, say $\frac{1}{2}$ to $\frac{3}{4}$ of a British battalion. The intervals between the redoubts will be about 1,000 yards. The heavy artillery will be placed in the intervals ; fire will be concentrated, but guns dispersed. In Russia, intermediate positions have already been constructed ; in Germany, instructions have been drawn up for their construction on the outbreak of war. Magazines will be dispersed, and not concentrated in the redoubts. The redoubts will probably contain some kind of conning tower for the observation of fire, etc. The proportion of direct-fire guns in a fortress will probably diminish. The mobility of artillery is strongly insisted on, but it is generally admitted that some at least of the heavier pieces must remain stationary. Many writers think that field guns should exist in increased numbers for flank defence, and to sweep the immediate front of the works ; but Russia is the only Power which has permanently organized field batteries for the express purpose of taking part in the defence of fortresses. She has five such batteries, one in each of the principal fortresses, which expand on mobilization so as to form three separate sortie batteries at each place. There is great divergence of opinions as to cupolas, both as regards their utility and their situation, but, so far, those that have been made are in the forts.

Cost.—As the dispute between the two systems of massive structures and cupolas, and of infantry redoubts and movable armament largely turns upon the question of expense, the point at issue being in reality which system will provide and maintain in action the maximum amount of fire, it will be of interest to give some idea of the cost of cupolas, etc. Those erected in France and Germany have cost from £7,000 to £12,000, according to the calibre of their guns, including carriage and erection, but excluding casemates, stores, etc., which General Brialmont estimates would double the cost. A Q.F. cupola costs about £3,000.

Lieut.-Colonel Grainiciano gives the following estimate for the cost of his scheme :—

Ordinary Main Fort—

Earthwork, masonry, etc.	£24,000
Armament, viz. :—	
1 cupola for 1 15-c.m. gun...	7,956
2 disappearing cupolas for 12-c.m. guns ...	8,416
2 cupolas for 21-c.m. mortars	11,904
5 disappearing cupolas for 53-m.m. Q.F....	4,900
2 Q.F. guns on casemate mountings... ...	740
	£57,916

Small Fort—

Earthwork, masonry, etc.	£20,000
Armament, viz. :—	
1 cupola for 1 15-c.m. gun...	7,956
1 disappearing cupola for 1 12-c.m. gun ...	4,208
1 cupola for 1 21-c.m. mortar	5,952
4 disappearing cupolas for 53-m.m. Q.F. guns	3,920
2 Q.F. guns on casemate mountings... ...	740
	£42,776

Ravelin Caponnière—

Construction	£8,000
Armament	3,616
	£11,616

Fortress of 20 kilomètres diameter, combining eight large and eight small forts—

8 large forts	£463,228
8 small forts	342,208
16 *ravelins caponnières*	185,856
	£991,292

To this must be added the cost of the glacis of the intervals, plantations, roads, and railways, which he estimates at about £240,000; and also the cost of the movable armament, which, in conjunction with M. Mougin, he estimates at 200 pieces costing £280,000. Colonel Grainiciano thus summarizes the total approximate cost of such a fortress:—

Construction...	£480,000
Fixed armament	511,392
Movable armament	280,000
Communications, etc., including the *material** of the firing railway	249,200
	£1,520,592

* The line is not to be laid until the place is threatened.

CHAPTER VII.

Coast Fortresses.

In a few cases the circumstances of coast fortresses are such as to require a regular girdle of detached land works, as well as a series of coast defences. The land works, and the general preparations for land defence, are then similar to those of land fortresses. More frequently, no regular prolonged attack by land is apprehended, and it is only necessary to guard against sudden raids by field forces without siege trains. In these cases sufficient land defence may usually be obtained by a field force with a small movable armament (possibly only field and machine guns), supported by one or two field, or other, works occupying tactical pivots.

It is, therefore, unnecessary to enlarge upon the fortress as a whole; we need only deal with the coast batteries, their adjuncts, and the special arrangements required for the defence of the sea front.

Coast Batteries: Their General Duties and the Conditions of Attack and Defence.

Coast batteries differ essentially from works designed to resist a land attack in several points. They can rarely have to sustain anything like a continuous siege, and even if they do, the fire to which they are exposed cannot have anything like the accuracy of that delivered by siege batteries, and they have little to fear from high-angle fire. On the other hand, they may be attacked by the heaviest projectiles in existence, and must be able to resist the immense bursting charges which they carry. Also, attacks upon them may be delivered very suddenly with the full power of the force sent against them, without any of the delay and consequent time afforded for preparation, which are inseparable from regular siege operations on land. Lastly, they may have (as when an enemy merely wishes to run past them) a very short time in which to produce the effect desired.

Thus they do not need a great amount of casemate accommodation for men or stores, but require heavy guns, good magazines with safe and easy arrangements for supply of ammunition, a few shelters for men, and the necessary artillery stores. In addition, they need sufficient arrangements for infantry defence to secure them from raids by landing parties.

The duties to be performed by coast batteries, and the general methods by which they are fulfilled, are described in some detail by Major Lewis (L., pp. 206—221), and need only be briefly mentioned here. They are—

1. To close the passage of a river or channel.
2. To protect a town or dockyard from bombardment.
3. To deny the use of an anchorage.
4. To defend a landing place.
5. To protect and close the flank of a line of land works. In this last case they may be subjected to attack from siege batteries, and must be designed accordingly.

In all these duties the guns may be assisted, where the local conditions are favourable, by a proper use of obstacles, which will delay the enemy under fire, or which debar him from the use of certain areas of water. These obstacles may be booms or submarine mines, but both are, as a rule, merely auxiliaries to the guns, and are useless unless covered by guns. Although the submarine mine may be fatal to a ship which comes to it, it must no more be considered the main defence than a series of land mines or fougasses would be considered the main defence of a redoubt behind them. Further, like obstacles on land, they must never be placed where they will in any way interfere with such movements as may be desirable for the defender's forces. Hence no scheme of defence should reckon upon their use except where the naval authorities do not object to their presence. It must be remembered that the coast batteries are in no sense our first line of defence, or even a second line (if by that is understood a line which can hold out after the destruction of the first), but that they are defences on the lines of communication which may have to be held unsupported for a short time, and may even serve as rallying posts for defeated *portions* of the defenders of the first line. The navy is our true first line, whether we consider it as a line of fortifications or as a line of battle. Hence no obstacles must be used which will hinder the free passage of the navy, or of the ships of commerce it has to protect, wherever the naval authorities deem such hindrance to be undesirable. Similarly, the batteries themselves only need such strength as is necessary to enable them to fulfil their respective duties during such time, and against such force, as the enemy is likely to be able to spare for their attack. The time must obviously vary, according to the situation of the place, and its proximity both to the enemy and to the waters where our vessels are most likely to be manœuvring. As to the force to be brought against it, both the number and individual strength of the probable attacking enemy must be considered. Major Clarke (C., Chapter XV.) gives a useful account of the amount of armour carried by various ships, and draws the conclusion "that comparatively few ships exist which are capable of engaging coast batteries armed with the 6-inch B.L. Some battleships and some coast defence vessels are suited for the purpose, but the cruiser class as a whole, and all vessels of European Powers likely to be found across the Atlantic, in the Pacific, in Indian or Cape waters, are disqualified from fighting any defences properly conceived and organized." Considering, however, the tendency which there now is towards the extension of the armoured cruiser class, and the protection given to its most vulnerable parts by the use of armoured decks, etc., care must be taken that we do not expect too much from our guns, even while we admit to the fullest extent the great disadvantage at which ships are placed in an attack on batteries. Coast defence guns may have to fulfil any of the following duties:—

1. Piercing armour, called "Primary Attack."
2. Attacking unarmoured and "protected" parts. } Called "Secondary Attack."
3. Attacking decks. }
4. Attacking men by shrapnel, machine, and field guns.
5. Attacking boats and small vessels by light pieces of all sorts.

The fire of guns intended for No. 1 should be reserved, so as not to waste ammunition, until it can be really effective, but sometimes, on account of their great range, these guns may be used for No. 2 at long distances.

The above duties are so varied that there will probably be some useful part which *any* available piece may play in an action. Q.F. and machine guns are particularly useful for Nos. 4 and 5 in defending landing places and mine fields. They should, if possible, be protected from the fire of ships, or they may be prematurely destroyed, and they should not be placed immediately in front of heavy guns, or their detachments may be injured by unburnt pellets from them. Under No. 2 might be included the attack of the projecting muzzles of heavy guns. Serious injuries may be caused at short ranges in this way. Probably the 5-inch B.L. or the 4·7-inch Q.F. would do serious damage up to 2,000 yards.

Armour may be wrought-iron, steel, or compound, but most probably the last. Guns may be required either to pierce or to shatter it. The ordinary rule as to penetration is that for every 1,000 f.s. of remaining velocity the penetration is one calibre in wrought-iron. Steel shell penetrate $\frac{4}{5}$-calibre in compound armour for every 1,000 f.s. of remaining velocity. These rules are practically correct up to about 2,000 f.s. velocity, but beyond that the penetration is really in excess of that given by them. Steel armour is sometimes considered as equivalent to about $1\frac{1}{2}$ times its thickness of iron, but, in fact, it fails rather by shattering than by penetration. It is obvious that if two projectiles of different calibre strike a ship with equal energy, the smaller, having less diameter, will have the best chance of penetration, while it will have the same shattering power. Hence the B.L. guns are far more effective against armour than the M.L., as appears from the following table, extracted from the official *Treatise on Manufacture of Guns, etc.*:—

Table of Remaining Velocities in Projectiles Fired with Full Charges.

Nature of Gun.	M.V.	At 500 Yards.	At 1,000 Yards.	At 1,500 Yards.	At 2,000 Yards.
R.M.L. Guns.					
17·72-inch	1,548	1,496	1,445	1,396	1,349
16 ,, ...	1,590	1,539	1,489	1,440	1,393
12·5 ,, Mark I.	1,445	1,385	1,329	1,276	1,227
12·5 ,, Mark II.	1,575	1,511	1,421	1,363	1,308
12 ,, 35 tons	1,390	1,246	1,196	1,149	1,108
12 ,, 25 tons	1,292	1,236	1,179	1,127	1,085

Table—continued.

Nature of Gun.	M.V.	At 500 Yards.	At 1,000 Yards.	At 1,500 Yards.	At 2,000 Yards.
R.M.L. GUNS.					
11-inch	1,360	1,255	1,199	1,149	1,106
10 ,, ...	1,379	1,294	1,228	1,170	1,118
9 ,, ...	1,440	1,322	1,236	1,160	1,097
8 ,, ...	1,384	1,306	1,213	1,136	1,074
7 ,, 7 tons	1,561	1,421	1,296	1,188	1,097
7 ,, 6½ tons	1,525	1,388	1,267	1,164	1,078
B.L. GUNS.					
16·25-inch...........	2,020*	1,965	1,902	1,840	1,789
13·5 ,, ...	1,960*	1,902	1,846	1,790	1,737
12 ,, Marks I. to V.	1,892	1,819	1,741	1,672	1,605
10 ,, Mark I.	2,100*	2,014	1,932	1,855	1,779
9·2 ,, Marks I. and II. ...	1,845	1,764	1,685	1,608	1,523
9·2 ,, Mark III.	2,050	1,958	1,870	1,786	1,704
8 ,, Mark III.	1,960	1,841	1,729	1,620	1,517
8 ,, Mark IV.	2,030	1,907	1,790	1,680	1,574
6 ,, 80-pr.	1,880	1,712	1,555	1,408	1,278
6 ,, Mark II.	1,660	1,536	1,419	1,309	1,206
6 ,, Mark III.	1,850	1,716	1,589	1,469	1.357

* Estimated.

It must be remembered, however, that the M.L. guns, although called obsolete, are still very useful within moderate ranges, and that their great shell-power makes them very effective against vessels which they can penetrate, while their curved trajectories give them special advantages in the attack of decks.

If an attack is ever made by sea on a great fortress, first-class ironclads, and possibly special designed vessels, would be used, and, therefore, these fortresses require the heaviest armour-piercing guns obtainable. The very presence of these guns might prevent an attack being attempted which otherwise might not be thought too hazardous in view of the results obtainable.

In most other cases the 6-inch B.L. and the 9-inch and 10-inch R.M.L. would suffice to beat off any ships likely to attack, but there are places where, owing to the proximity of a foreign squadron, or to the great damage which an enemy might do if he could put fairly powerful vessels within moderate range, it would be desirable to mount more powerful pieces, such as the 9·2-inch or 10-inch B.L. The bulk of the armament would, however, be of the smaller natures in all such cases. Guns of less power than the 7-inch R.M.L. should not be depended on for fighting ships, as there is a growing tendency to spread out the armour again over the ship's sides, in order to keep out the shells of Q.F. guns. The smaller guns will still be useful against boat attacks, landing parties, etc., in places where they can be protected from being dismounted by the fire of the ships. High-angle fire will be especially valuable to prevent vessels from anchoring either to make their fire more effective, or for the purpose of laying out countermines, etc. For this kind of fire the 9-inch R.M.L. is being adapted, with an angle of 35° elevation, which may, perhaps, be increased to 70°. When directed by the position-finder excellent effects are obtainable.

The Zalinski, or some other gun firing large high-explosive shells (see p. 128), may also be found of great service where the hostile ships must come in to short ranges. Even where the nature of the place does not render an attack at short ranges necessary, it is generally agreed by sailors that their best chance lies in coming in close and delivering as heavy and as rapid a fire as possible.

Dirigible torpedoes, such as the Brennan, may also be very important auxiliaries, but their range and general scope is limited. Their proper use is where the enemy *must* pass within moderate range through a certain water area. They would generally cover the front of a mine-field.

Harbour Defence Vessels must not be relied on. It is almost inevitable that such vessels should be under the command of the admiral of the station, and with him must rest the decision as to where and how he will employ them. He may rightly deem it necessary to strengthen his squadron by every available ship to defeat the enemy at sea, and, therefore, at the moment when the land commandant is preparing for an attack by one or two cruisers, the harbour defence vessel may be summoned to sea to assist in fighting the enemy's main squadron. On this account it is sometimes urged that certain vessels should be placed absolutely under the orders of the commandant of a coast fortress; but it seems hardly probable, and certainly anomalous, that such a course should be adopted by an empire whose very existence depends on its navy. There is, however, one case where, without naval assistance, it will probably be impossible to guarantee absolute security, namely, where shipping in harbour has to be protected by batteries on a channel leading to it. Where the port is an important one, it is improbable that British naval authorities will sanction the entire blocking of the channel by submarine mines and booms. Torpedo boats and fast gunboats may attack in considerable numbers, and their speed is so great that they will not remain long under effective fire. If, therefore, they press their attack home, supported, perhaps, by the fire of larger ships lying outside, although they may suffer severe loss, it is probable that some of them might effect an entrance, and do considerable mischief, unless a naval force is at hand to co-operate with the batteries.

It is sometimes urged that *all* defence should be left to the navy, but this seems hardly wise or economical. No doubt it is useless to try to provide fortifications of such power that if our naval supremacy were altogether lost we could still resist; but if no fortifications exist, although the ultimate issue of the war might still be successful, our coasts would be liable to insult and injury during the temporary absence of protecting squadrons, and coal stores, docks, etc., might be destroyed, or injured in such a way as to cause serious inconvenience to our ships. The provision of a few guns of moderate size in the right places may obviate all this. Thus on the one hand it is necessary to guard against hampering the fleet by requiring costly vessels to do duties which might be equally well done by a much less costly battery, and on the other against yielding to the natural desire of the civil population of every place to see massive works and heavy guns supplied to protect it against attacks by ironclads which in reality would never be made. Finally, naval opinion should always be obtained as to the nature and amount of coast defence required at any particular station (L., 195—221).

Preparation for Defence.—To prepare a coast fortress for defence, the steps detailed in Chapter I. (pp. 68—70) must be taken as far as applicable to the particular case in hand, but the points which are most likely to need consideration and additional provision are:—

(1). Communications by road, rail, telegraph, telephone, etc.

(2). Overhead cover for observing and fighting stations of officers.

(3). Preparation of the shelters for occupation by men.

(4). Provision of hut, tent, or billet accommodation for garrisons. For this purpose it is necessary to know what the actual garrisons will be, and not assume that there will be three reliefs for every gun. As a rule, it is impossible (and frequently quite unnecessary) to provide so many reliefs. Every battery is now provided with a "manning table," which shows the number of artillerymen required. In some batteries there may be a few infantry, and there will usually be a full force of infantry and artillery encamped somewhere within the fortress area.

(5). Electric lights and their accessories for submarine mines. Those for the guns will, perhaps, be prepared by the artillery.

(6). Mines must be laid out in the approved fields.

Above all, it is necessary that clear and careful arrangements are made to ensure thorough co-operation between the various portions of the defence. Naval, artillery, and submarine-mining officers may all have to take an active share in the fight, and care must be taken that each fully understands his own share. The lights under the control of one officer must assist, and not hinder, the others; it must be arranged that there shall be no danger of a search light being thrown on to one of the batteries, and so showing it to the enemy; of a light being thrown in the face of vessels manœuvring in defence, nor of defence vessels being mistaken for the enemy and so fired on by guns or blown up by mines; guns for the defence of a mine-field must be supplied with such information as to the positions of mines that even in the dark they may be enabled to open an effective fire if a signal is received showing that the enemy is interfering with them.

CHAPTER VIII.

TYPES OF BATTERIES AND GUN-MOUNTINGS.

WHATEVER form of battery is used, a few general principles are applicable. The battery, consisting as it does mainly of positions for guns, is, in fact, made up more or less by combining together a few definite units. For each gun there is required an emplacement of very definite shape and dimensions, which can vary little, if at all. The amount of magazine accommodation admits of very little variation for the guns of any particular calibre. Each gun detachment requires a certain amount of shelter and of storage accommodation. Thus a new design for a coast battery consists of adapting in the best way to the local circumstances of ground, etc., a number of independent units, each composed of a gun emplacement with its necessary adjuncts.

Slight varieties may be introduced in the shape of shelters, stores, etc., and in the mode of supplying ammunition to the guns, but little change can be made in the emplacements. In any emplacement there must be just enough room for working the gun conveniently, and all the surrounding work must be as solid and substantial as possible.

In open batteries, the guns may be from 100 feet to 100 yards apart, but the distance now usually considered best is about 150 feet from centre to centre. All the more important guns will be directed by position-finders, range-finders being also used as auxiliaries.

Existing batteries may belong to any of the following classes :—

1. *Open Batteries,* in which there are three classes of mountings: (*a*), barbette ; (*b*), disappearing ; (*c*), high-angle.

2. *Open Batteries with Shields.*—All these are designed to be covered, if necessary, with timber or iron overhead. In many cases the iron covering has been fixed, and they then become

3. *Open Batteries with Shields and Permanent Overhead Cover.*—Practically a form of casemate.

4. *Masonry Casemates* with iron shields.

5. *Continuous Iron-fronted Casemates.*

6. *Curve-fronted Casemates*, with two ports for each gun and a turn-table.

Nearly all coast batteries (at least in British possessions) in future will be of the first class. Casemated or shielded batteries will only be built in very special cases. When used, they will generally take the cupola or turret form, as is the case with some German batteries. Before proceeding with details of a design, it is necessary to mention the different classes of guns and mountings that are available.

The guns on travelling mountings already mentioned (Chapter III.) are, of course, available where required, but some of the following, on fixed mountings, would furnish the main defence, those on travelling carriages being utilized for defence of landing places, mine-fields, etc. The maximum angle of elevation and depression is given in the published lists of ordnance, but the depression is ordinarily 5°, often 7°, and sometimes 15°. The ordinary elevation is 15°, but with some recent mountings it is increased to 20°.

Q.F. Guns.—6-pr. Q.F. on Cone Mounting.—For the Hotchkiss and Nordenfelt 6-pr. Q.F. there is a cone mounting (*Plate* XI., *Fig.* 1) with bullet-proof shield and also a 3-inch plate at the trunnions. It is bolted to a steel ring, which is sunk in a concrete bed 12 feet wide, and not less than 2 feet thick, and it fires over a parapet 3 feet high. In some batteries, a wooden platform 5 feet 3 inches × 8 feet 3 inches has been provided, but this will not be repeated. The 6-pr. may be considered sufficient up to ranges of about 1,500 yards.

4·7-inch Q.F.—Where greater range is required, the 4·7-inch Q.F. should be used, which is effective up to about 2,400 yards. It fires a 45lb. shrapnel shell, containing 225 balls at 14 to the pound, and also a common shell of 45lbs., and is mounted as shown in *Plate* XI., *Fig.* 2.

6-pr. Q.F. on Saddle Mounting.—There is also a "saddle," or embrasure, mounting for the 6-pr. Q.F. (*Plate* XI., *Fig.* 3) which can be used in the ports of casemates. When not required, the gun is drawn inside and slung at the side of the port.

Guns on Barbette Mountings.

In some places guns still remain mounted on one of the old forms of carriage which only admit of fire over a low parapet, so that the gunners are greatly exposed. These mountings are the *rear-chock* (*Plate* V., *Fig.* 2) and *common-standing* carriages, firing over about three feet, and the *dwarf* carriage and slide, firing over parapets not exceeding four feet three inches (*Plate* XI., *Fig.* 4).

R.M.L. Guns from 64-*pr. to* 12·5-*inch.*—On the two former carriages, the 64-pr. R.M.L. is mounted; on the last, all R.M.L. guns, from the 64-pr. to the 12·5-inch (38-ton), can be mounted. Emplacements for 10-inch and 11-inch guns are provided with a step seven inches high, called a *fixed loading stage*, to facilitate their loading.

The "blocked-up" and similar mountings (page 83) enable guns to fire over parapets six feet, or with some of the heavier guns, five feet, above the racers.

Sunken Loading-way and Movable Stage.—Loading Stage Fixed to Slide.—An improved form of emplacement is that with *sunken loading-way* and movable stage. In these, round the concrete drum on which the gun is placed, there is a sunken path or loading-way, seven feet below the crest, in which the gun detachment can work, except the men entering the charge into the gun or sponging out. For them, a *movable loading stage* was provided, but in the latest improvements the stage has been fixed to the slide, to which a convenient loading derrick is also fixed (*Plate* XII., *Fig.* 1). When the charge has been placed in the gun, the men can step down and complete the loading by pulling ropes attached to the rammer. The traversing gear is arranged so that the men can work it from the loading-way.

6-*inch B.L. Barbette.*—A similar mounting (*Plate* XII., *Fig.* 2) has been adopted for the 6-inch B.L., but the sunken loading-way is only six feet below the crest.

8-*inch B.L. Barbette.*—There is another, which is somewhat similar, for the 8-inch B.L. barbette, but as only a few specimens of the gun or its mounting exist, it is not worth while to give a drawing of them.

In future, all barbette emplacements for R.M.L. guns will be made to suit mountings of this type (L., p. 226) For actual dimensions, the latest I.G.F. circulars, etc., must always be consulted, as minor alterations are liable to be introduced from time to time.

Barbette Mountings on Level Floors.—9·2-*inch and* 10-*inch B.L. Barbette.*—The latest barbette mountings are for the 9·2-inch and 10-inch B.L. guns, and do not require any concrete drum above the general level. They enable the guns to fire over 7ft. 6in. or 8ft. parapets (*Plate* XII., *Figs.* 3 and 4).

10·4-*inch and* 17·72-*inch R.M.L.—Special mountings* exist for various guns, such as the 10·4-inch R.M.L. and the 17·72-inch R.M.L. (100-ton), but as these are special patterns for guns which will not be reproduced, and as very few of them exist, it is unnecessary to describe them here.

Mountings in High Positions.—64-prs. R.M.L. and 6-inch B.L. on High Sites.—Plate XIII., *Fig.* 1, shows a mounting for the 64-pr. in high positions; and *Fig.* 2 shows a Vavasseur mounting for the 6-inch B.L. in high or very confined positions.

Guns on Disappearing Mountings.

There are two systems of disappearing mountings, namely, the counterweight or Moncrieff system, and the hydro-pneumatic system. No more of the former system will be made, but they are at present in use for the 64-pr. R.M.L. firing over 9 feet 4 inches, the 7-inch R.M.L. firing over 11 feet (*Plate* V., *Fig.* 4), and the 9-inch R.M.L. firing over 12 feet 6 inches, but only two of the last exist. The hydro-pneumatic system is applied to the 6-inch B.L. firing over 9 feet (*Plate* XIII., *Fig.* 3), the 9·2-inch B.L., firing over 8 feet $6\frac{3}{4}$ inches (*Plate* XIII., *Fig.* 4), and the 10-inch firing over 8 feet 10 inches.

All these mountings are in pits with concrete walls and floors. The pits should not be closed at the rear unless exposed to all-round fire. With the H.P. mountings, the pit is covered by a turtle-back shield with a slot in it, through which the gun rises and falls. In all-round pits this slot can be closed, when the gun is down, by iron plates, so that the pit may be shut up securely and the gun fittings stored within it.

There is also an hydraulic mounting for the 13·5-inch B.L., which is of generally similar description to the above, but very few guns are likely to be mounted on it, as it is not now considered necessary to have such heavy guns for coast batteries.

Guns on High-angle Mountings.

A mounting has been adopted for the 9-inch R.M.L. which allows of fire up to 70° elevation.

Some of the old carriages of 9-inch R.M.L. guns had previously been adapted to allow 35° elevation to be given. Emplacements for the 9-inch R.M.L. on the high-angle mounting are shown in *Plate* XIV.

Guns on Casemate Mountings.

Guns in casemates are mounted on traversing slides, working on A pivot racers, the essential variations in the mountings depending on the system adopted for checking recoil. In the older mountings, the recoil is checked by compression plates, but in the later ones it is taken by hydraulic buffers, and in both cases the shock is communicated through the slide to the racers. Both these mountings are for R.M.L. guns from seven inches upwards. The only B.L. gun mounted in casemates is the 12-inch (*Plate* XV.), which has a special arrangement called a *yoke mounting* to take the recoil. In this case hydraulic buffers are used, but they are attached to the yoke so that the recoil is not taken by the racers, but by the roof and floor of the casemate.

The Q.F. saddle mounting, for use in the ports of casemates, has already been mentioned (p. 125).

Guns for New Batteries.

In designs for new batteries, the guns to be used will usually be selected from the following :—

Barbette.—R.M.L. guns from 7-inch upwards, with sunken loading-way, with loading stage and derrick fixed to the slide (*Plate* XII., *Fig.* 1) ; B.L. guns, 6-inch, on similar mounting (*Plate* XII., *Fig.* 2), 9·2-inch and 10-inch on barbette mountings (*Plate* XII., *Figs.* 3 and 4).

Disappearing.—6-inch, 9·2-inch, 10-inch, B.L. on H.P. mountings (*Plate* XIII., *Figs.* 3 and 4).

Very High Sites.—6-inch B.L. on Vavasseur carriage (*Plate* XIII., *Fig.* 2).

High-angle Fire.—9-inch R.M.L., and perhaps some of the heavier R.M.L. guns, on high-angle mountings.

Zalinski Pneumatic Gun.—Some form of this gun might be very valuable in special cases, but its limited range has prevented its adoption for general purposes, and, in fact, it is at present rather a competitor with the locomotive torpedo than with the ordinary gun. The Zalinski 15-inch can also fire 10-inch and 8-inch projectiles, but with the largest its fire has been very far from accurate. Its ranges are as follows for these three calibres :—

With a burster of 100lbs. of high explosive	...	5,000 yards.
,, ,, 200lbs. ,, ,,	...	4,000 ,,
,, ,, 500lbs. ,, ,,	...	2,000 ,,

Its rate of fire is about one shell a minute for the first 10 rounds, after which eight minutes are required for each round. Its fuzes are electrical and can ignite either on a direct hit, or under water after suitable delay if direct hit is not obtained.

Guns on Railway Mountings.—Where the coast is suitable, guns may probably be economized by using railways, while at the same time the defensive power will be increased. A paper read by Lieut. Girouard, R.E., at the Royal United Service Institution in April, 1891, presents this idea on a very wide scale. The question is too much a matter for argument to be fully entered into in these notes; but in any case, there is no doubt that railways or tramways might in many cases be made useful auxiliaries, especially in the defence of mine-fields and landing places. Light pieces can be easily mounted for use on rails, and special mountings could be made to take heavier guns if desired. A trolly for the 6-pr. Q.F. is under trial, and the 4-inch B.L. has been successfully fired on a Vavasseur mounting on an ordinary railway trolly on ordinary rails.

As regards the power of projectiles against which protection has to be provided, Major Lewis has given a summary of results hitherto obtained (L., pp. 185—194). At the bombardment of Alexandria (1882) no projectile penetrated more than 20 feet of sand. No masonry can sustain the fire of heavy guns without very serious injury, and we may be confident that in future no masonry casemates will be erected. Where they now exist, security can only be obtained either by armour-plating over them or by filling alternate casemates with concrete, etc., so as to increase the traverse protection. In some cases, the magazines can be sufficiently protected by filling up the ditch, so as to put them entirely below ground, or by filling outer stores, etc., with concrete, so as to have some 50 feet of solid masonry outside the cartridges. In future designs the magazines should all be below ground, and under a traverse or parados. They will then be secure, as vertical fire has not to be guarded against.

Earth parapets should be given very gentle slopes, but if the site is too cramped to allow of this, layers of concrete not less than 18 inches thick may be introduced. This expedient should, however, rarely be necessary.

CHAPTER IX.

Design of Coast Batteries.

It has already been pointed out (p. 124) that the design of a coast battery, when once the site has been selected, consists mainly in adapting certain more or less rigidly-defined units to the ground.

Site.—The selection of the site is generally open to very little choice, its limits being fixed by the necessity of defending certain definite water areas. Within those limits the points to be considered are: (*a*), the foundations obtainable for the heavy masses of concrete and the guns they are to carry; (*b*), the height above the sea at which the battery can be constructed; (*c*), the facilities for directing its fire by position-finders. Where a high site is obtainable, it is advantageous, because it is very much more difficult for vessels to deliver effective fire, either with common shell or with shrapnel, against it; and further, if the site is *very* high, it facilitates plunging fire on the decks, but unless the height is 500 feet or so, it has no great effect in this direction, especially with the B.L. guns, on account of their flat trajectories. At a height of 100 feet the trajectory of machine guns at 1,000 yards (about the limit of good shooting for them on ships) is nearly flat. Therefore, this height (or better, 150 feet) should, if possible, be given to a barbette battery, which can be approached within 1,000 yards, in order that an ordinary parapet may give good protection against machine guns. On lower sites disappearing mountings would be used.

The risk a barbette battery runs from the enemy's shells is shown by Major Clarke (C., 178—196) to be very much less than would theoretically appear probable. At Alexandria the *total* hits on the parapets of all the works (excluding shrapnel and segment shell) was 1 in 19 rounds, and of these a large proportion were on the exterior slope, which were, of course, of no account as regards the vulnerability of the gun and detachment. The crest hits were only

11 out of 1,620 of 7-inch shell and upwards. To obtain searching effect, as for shrapnel, ships must fight at long distances. Even with the 10-inch R.M.L., and a 70lbs. charge, a ship must be at 1,050 yards range to secure a *horizontal* line of fire against a battery 100 feet high, and at 2,950 yards to secure 6° descent. With B.L. guns the distances must be much greater.

Casemated Batteries.—As casemate batteries will rarely be constructed in future, it is not proposed to discuss their designs. They are fully treated by Major Lewis (L., pp. 233—251 and p. 267).

Open Batteries.—The best form to give to an open battery is to form a gently sloping parapet (not steeper than $\frac{1}{7}$ if possible), and to put the guns in it, letting their emplacements form a kind of pit open to the rear (see *Plate* XVIII.). The emplacements would usually be about 150 to 200 feet apart. Behind them the battery may be left completely open, or a parados may be constructed. This will depend mainly upon the nature of the background, but, as a rule, the parados would not be worth its expense. Every means should be taken to render the battery invisible from the sea by allowing no sharp angles, by colouring masonry and guns, by planting, etc., etc. (L., 279—280). If there is a parados, it should be made with a gentle slope, or should be at least 60 to 90 yards from the crest of the work, so that it may not throw back fragments of shells bursting on it into the emplacements.

Positions of Magazines and Shelters.—The magazines and shelters may be placed under the parapet or traverses, between the guns. The emplacements themselves should be as solid as possible, allowing each gun the greatest arc of fire obtainable, and having their side walls carried back no further than necessary, in order that there may be as little danger as possible of their catching shells which have passed over the gun.

Emplacements.—In, or close to, the emplacement there should be some cartridge recesses for use in emergency. Of course, care must be taken to place them in the safest position obtainable consistent with easy access. Shells may be placed in similar recesses or standing round the front of the emplacements (L., 163—165). On the right of the emplacement there must be a recess 2 feet high × 6 inches wide × 5 inches deep for the "firing plug," which the gun captain has to insert in the circuit before the gun can be fired electrically. At some place near the rear of the emplacement, but out of the way of the ammunition supply, another recess is required for the dials, which show the amount of training and elevation to be given to the gun when its fire is being directed by position-finder. In new batteries this recess should be 5 feet 6 inches high × 3 feet 3 inches wide × 12 inches deep, so as to accommodate the electric battery as well as the dials.

Lifts must open *near*, but not into, the emplacement. On each flank of each emplacement (or of each group* if the guns are close together) there should be an observing post, where a man can stand to watch the effect of the fire. If possible these posts (which may be utilized for range-finders) should have bullet-proof, or at least weather-proof, cover, but generally this might be actually erected when wanted. Of course, this does not apply to high-angle fire batteries, whose fire is usually observed, as well as directed, solely from the position-finding stations.

In the construction of emplacements, *too much care cannot be given to the laying of the racers and training arc*, to ensure perfect accuracy (L., 269—276), or to the quality of the concrete, especially under the muzzle. The lip of the emplacement for guns on H.P. mountings must be carefully designed to suit the curve taken by the gun in its descent, and in all emplacements the concrete in front must be carried out far enough to give ample protection against the blast of the gun, say five feet beyond the muzzle of the 6-inch, and seven feet six inches beyond that of the 9·2-inch and 10-inch. B.L. Finally, it should be sloped down for at least another foot in the 6-inch emplacement, and two feet in the others, and thence it may be finished with a vertical face (*Plates* XVI. and XVII.).†

In all-round pits there must be recesses five or six feet wide, six feet three inches high, and seven or eight feet deep, at intervals, to allow of loading.

In all emplacements there must be four or five ring bolts countersunk into the wall, three feet above the floor, to assist in mounting and moving the gear.

For fuller details and exact measurements see L., Chapter V.

In connection with all emplacements for H.P. mountings, some accommodation must be allotted for the reservoirs used for charging the cylinders. This would usually be given in the artillery store.

* A "group" consists of from one to five guns under one subaltern, and directed by one position-finder (when the P.F. system is used). It is usually two guns about 150 feet apart, except in casemated batteries, where, the guns being closer, more can be grouped together (see Chapter X.).

† By a lithographer's error, in *Plate* XVI. (Section on AB) concrete, instead of earth, has been shown in the little triangle at the top of the exterior face.

The emplacements having been provided for, the other accommodation required is as follows :—

Accommodation for Men.

Shelters.—It is unnecessary, in ordinary batteries, to provide living accommodation for the garrison. While awaiting a possible attack they can be encamped or quartered close at hand. The attack, when made, will not be of long duration (except in the case of a deliberate attempt to reduce a large fortress, such as Gibraltar or Malta), and, therefore, it is only necessary to have some *shelters* in which men not actually employed at any time may be securely covered. Whether a prolonged naval attack (not a blockade) will ever be carried out under any circumstances is a doubtful point, and the cases where it might have to be guarded against are so special that they need not be dealt with here. Such shelters as are provided in the ordinary coast battery must be bomb-proof, and must be provided with doors, windows, and fireplaces. Grates need not be set in them beforehand. These shelters may be utilized in peace as stores for machine and field guns.

Guard-house.—A *guard-house* of the ordinary type is usually needed for peace purposes, and gives sufficient accommodation for the men in charge.

Cook-houses, etc.—The arrangements to be made for the war garrison must be considered in case any special preparation for latrines, cook-houses, etc., may be required. On a confined site it might sometimes be advisable to put in a concrete floor, with good drains, on which these necessary structures might be erected when required.

Water Supply.—*Water supply* is most essential, and must be carefully considered, so that arrangements may be made which cannot be interfered with by landing parties.

Accommodation for Ammunition and Artillery Stores.

Large *magazines* would seldom, or never, be required in a coast battery, but sufficient secure storage must be provided for 200 rounds per gun. Each nature of gun, and usually each gun, or, at least, each group, should have its own cartridge and shell stores.

Shells.—In calculating the space required, it must be remembered that R.M.L. and R.B.L. shells of 7-inch and upwards, and B.L.

shells of 6-inch and upwards, are stored on end. Smaller shell are piled. Shot and Palliser shell may be stored in the open.

Cartridge Cylinders.—Cartridges for heavy guns are packed in zinc cylinders, each of which contains from a quarter of a charge to a complete charge, according to the calibre of the gun. They are stored in piles, not exceeding three cylinders. If higher stacks are required they must be carried on skidding and frames. For space occupied by cylinders see L., 143.

Metal-lined Cases.—As to cartridges for smaller guns see page 104.

Shell and Cartridge Stores.—These should not have *less* than six feet or six feet six inches head room, and there should be space for a good clear passage down the middle to facilitate the issue of ammunition. Of course, every cartridge store must be entered through a shifting lobby (which should, however, not give access to the shell store, the shells being of iron), and the usual lighting arrangements must be made (p. 105).

Fuze and Tube Shelf.—Shelves for fuzes and tubes should be provided in all shell stores (L., 154).

Supply of Heavy Ammunition to the Guns.—Cartridges should be conveyed under cover to the guns if possible. With the heavier guns this is arranged by means of lifts, delivering either into the open close to the emplacement, or better, into a bomb-proof shelter, the entrance to which is from, or close to, the emplacement. With 6-inch B.L. guns the arrangement shown in *Plate* XIV. is suitable, the cartridges being lifted by hand up a height of three or four feet at the issuing hatch (see *Plate* XVIII.). Shells are either sent up a lift or conveyed on a trolly to the guns. Sometimes they are raised by a derrick instead of a lift from the store level to that of the emplacement. They are usually sent from the shell store to the lift or derrick on a trolly, but sometimes instead of a trolly an overhead traveller is provided.

The lifts may be circular, or of the "tray" pattern (L., 155—163). The former takes up single projectiles or cartridges vertically, the latter takes several horizontally on successive trays. The former, therefore, requires a larger delivery opening, and cannot maintain so rapid a supply, provided the tray lift is not, as might occur with very heavy guns, overloaded.

Care must be taken that the top of the lift is not exposed to fire.

If possible, every ammunition store should be provided with three alternative modes of supply to the guns, viz., by lift, by derrick, and by hand.

Q.F. and Small-arm Ammunition Stores and Recesses.—The storage of Q.F. and small-arm ammunition has already been dealt with (p. 104).

Ammunition recesses close to the emplacements will be especially necessary for Q.F. guns (L., 164—165).

Laboratories, etc.—For *laboratories, etc.*, see page 105.

As to *magazine details in general*, see L., Chapter III.

Lamp Room.—A *lamp room*, for storage and cleaning of lamps, must be provided conveniently near the lamp passage.

Artillery Stores.—A *general artillery store* for the battery is required for reserve and unserviceable stores, skidding, etc.

A *store for small stores* is also required for the removable fittings and spare breech-pieces, etc. It should be fitted with shelving, etc., as follows:—Each 6-inch B.L. requires three feet six inches run of shelving, as in *Fig.* 5. For every 10 guns or less, add three feet

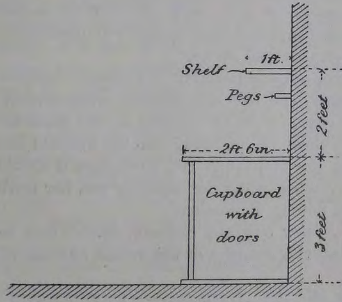

Fig. 5.

six inches of shelving, to give space for a vice with a cupboard about two feet high under it, instead of three feet; and also add a space of three feet six inches for storing breech screws on the floor. For 9·2-inch and 10-inch B.L. guns, provide the same accommodation, only reading five feet and six feet respectively throughout, instead of three feet six inches (L., p. 289—290).

A *side-arm and tackle store* is required, which must admit of easy withdrawal of the long side-arms. Sometimes pegs and hooks along a passage may be provided instead of a separate store, or the general store may be utilized (L., p. 290).

Other Accommodation.

A *smiths' shop* must be provided, and, as repairs may have to be carried out during action, it must be given bomb-proof cover. It should be about 20 feet × 16 feet × 10 feet 6 inches high.

Sometimes a *workshop* 12 feet × 16 feet × 10 feet 6 inches high may be added (L., p. 290). In large batteries this is a necessity.

Pumps and Reservoirs for H.P. Mountings.—These must be provided for either in a separate store or in one of the R.A. stores.

Range-finders.—At least two sites for range-finders should be provided, one on each flank of the battery. These are merely recesses in the parapet with a brick pedestal in them to give a base on which the instrument stands. It has been decided that they are not to be permanently roofed. Close to them there should be shelters for the fire commander to occupy when the P.F. system is not used.

It is impossible to deal with the communications and other accommodation connected with range and position-finders without trenching on confidential matter.

Electric Light.—Accommodation for electric lights will be needed in some batteries, and this will include arrangements for the light itself, and an engine-room for working it, but exact details have not yet been laid down (L., p. 305). No light should be nearer to the officer making use of it than 100 yards, and it should not be more than 100 feet above water for artillery use, nor more than 25 feet for submarine mining, if possible.

Submarine Mining Observing Stations, etc.—Where mine-fields are laid down, observing stations, or test rooms, or both, will be required (L., p. 304).

Shelters for Movable Armament.—Where movable armament is provided, whether for defence of a land position or for that of a landing-place or mine-field, storage room must be arranged for it and its ammunition. For the guns, either special sheds must be erected as in land works, or the shelters for men may be utilized for all, or some, of them, as they will be removed before the men need the shelters.

Combination of Above.—*Plates* XVI. and XVII. show the requirements for a single 6-inch and a single 9·2-inch B.L. In addition to the accommodation there shown, there must be provided for a complete battery, two range-finder stations, a smiths' shop, R.A. general store, and guard-house, and such of the other accommodation mentioned above as may be necessary. *Plate* XVIII. shows a 4-gun battery, without smiths' shop, guard-house, or gorge defence. The water supply arrangement would, of course, vary in each case.

Q.F. and Machine Guns.—Q.F. guns may be mounted in a separate series of emplacements with the necessary stores and shelters, or they may be placed on the flanks of, or among, heavier guns. This must depend entirely on the local circumstances.

Similarly, machine guns may be mounted on parapets between the heavy guns or in separate positions as required.

The armament of a coast battery will seldom include more than one or two heavy guns (9·2-inch or 10-inch B.L.), and will generally have from two to four 6-inch B.L., which may be on the flanks or not, according to circumstances. It must be remembered that it is desirable to allow the heavy gun as wide an arc of fire as possible, and it should be able to engage the enemy as early as possible. Hence, in defence of a channel, it might probably be best to place it in the centre, or on the outer flank. No general rule can be laid down, except that the engineer's business is to enable the artilleryman to make the best use of his weapons, and that a convenient grouping of guns may economize officers, as it is undesirable for one group officer to have more than one nature of gun to deal with.

Gorge.—The gorge defence will necessarily vary with circumstances. Occasionally, no defence is required, and a mere fence to keep out intruders is sufficient. Ordinarily, however, it will be necessary to provide means of resisting attacks by parties landed in order to take the guns in reverse and capture and destroy them. Such parties might have field artillery, but nothing heavier. It will, therefore, be sufficient to provide a gorge parapet which will resist field artillery, and will allow an efficient rifle defence to be made. It may, in some sites, have to be raised sufficiently to defilade the gun emplacements, or a parados may have to be provided for this purpose.

The parapet should be of the Twydall type, but no great expense need be incurred to cover the palisade, as field guns will do it little injury. The palisade and rifle defence should be carried right round the battery if there is any possibility of landing parties creeping round to the front.

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PAPER IV.

SHORT ACCOUNT OF THE BRIDGING OPERATIONS OF BENGAL SAPPERS WITH THE HAZARA FIELD FORCE, 1891.

By Major P. T. Buston, R.E.

On February 9, 1891, the Pontoon Section of the Bengal Sappers and Miners, consisting of 1 British officer, 2 native officers, 2 British N.C.O.'s, and 70 native N.C.O.'s and sappers, left Roorkee by rail for Attock, to collect boats and materials there previous to proceeding to join the Hazara Field Force, which was being formed at Derband. Derband is on the Indus, and about 60 miles above Attock. The detachment took with them rope, blocks, tools, and some chesses; pontoons and the other stores were left behind. By February 15th, 11 large country boats, 1 small country boat, 1 rowing dinghy, and sufficient trussed beams, cross beams, and chesses had been collected and loaded in the large country boats. The small country boat carried supplies for the men, as, until we joined the force at Derband, we had to make our own arrangements for food. One hundred native boatmen had also been engaged, and the civil authorities had been warned that we should require 150 coolies per diem to tow the boats.

The reasons for starting from Attock in place of anywhere higher up the Indus were as follows :—

1. It was on the line of rail.

2. There were a certain number of stores there, with which the pontoon section had been practising the previous November.

3. It was at the junction of the Cabul and Indus rivers, and while there is little or no boat traffic on the Indus above Attock, there is a good deal on the Cabul river, as the current is not so rapid, and the river much deeper. We were able to hire a few boats at Attock, but the remainder all came from villages on the Cabul.

Before proceeding further, it is, I think, best to say a few words about the Indus. At Attock, in the winter, when the water is at its lowest, the river is about 200 yards wide, and has a current varying from five to eight miles an hour; the river is here confined by rocky banks about 400 yards wide. The river is low from October to March; in April it begins to rise, on account of the melting snow, and attains its maximum in June, as a rule. Immediately above Attock, the river bed widens, and in some places is as much as two miles across; through this, in the cold season, the river wanders in two or three channels, which meet every here and there, and then diverge again. The bed consists of sand and rounded boulders. The current is about three or four miles an hour, except at the rapids; on an average, there is a rapid every mile. There are 37 rapids between Attock and Torbela, but, with the exception of the one at Attock, none of them are dangerous, and are only difficult to tow a boat up because very often the head of the rapid is on a curve, with the channel in the centre. Above Torbela, the bed narrows, and at Derband (*Plate* I., *Fig.* 1), some 25 miles higher up, the river is only from 100 to 200 yards wide. There are eight rapids between Torbela and Derband; of these, the one opposite Amb is dangerous. Above Derband, the character of the river changes, and it becomes deep and narrow, with a current of about two miles an hour, except at the rapids; these rapids occur, on an average, every other mile. The banks and the bed consist of solid rock, with well-worn rounded boulders scattered about, and the walking, consequently, is very bad. So far as could be ascertained from native information, the river maintains this character as far as Thakot.

The materials taken were boats, trussed beams, baulks, chesses, blocks and tackle, rope, both country and Manilla, and tools.

The boats were the ordinary country boat which is in use on the Cabul and Indus; they are of two patterns, but do not vary much as regards size or capacity. One pattern has a square bow and stern, the other a pointed bow and stern (*Plate* I., *Figs.* 2 and 3); both patterns are flat bottomed. They are rowed by two long oars at AA, and steered by two similar oars at BB. The oar consists of an ordinary spar, 15 feet long; the butt is shaved down for a handle, and on to the tip is lashed a piece of board $5' \times 10'' \times 2\frac{1}{2}''$, which acts as a blade (*Plate* I., *Fig.* 4). Two men are required for each steering oar, and four men for each rowing oar.

The trussed beams were those used in the Government boat bridges; they are $30' \times 7'' \times 7''$.

The baulks were $14' \times 7'' \times 7''$ of deodar.

The chesses were partly Roorkee pattern of teak $11' \times 1' \times 1\frac{1}{2}''$, and partly Punjab pattern of deodar $14' \times 1' \times 3''$.

The double-wheel metal travelling block with which the flying bridge was worked consisted of two gun-metal sheaves AA set in an iron shell (*Plate* I., *Fig.* 6). The sheaves are grooved to run on the 3-inch steel-wire cable. At the end of the block is a ring, to which is fastened the ropes from the raft.

On February 16th, we started the boats off as the coolies arrived—20 men per boat, viz., 8 boatmen and 12 coolies. Four boatmen were required for the steering oars, and the other four looked after the towing rope, taking care that it did not get foul of the boulders, etc. All the coolies were put on the towing rope, which was 3-inch Manilla. The boatmen had stated before we started that they were not in the habit of taking heavily-laden boats up the Indus, and though our boats were not heavily laden, still they drew two feet six inches, and they said they considered it too much. But as there was only pack traffic to Derband, and as the trussed beams and baulks were too heavy for pack animals, we had to tell them that the boats must go laden as they were. However, on the evening of the 16th, I began to think that possibly they might be right, as when, having seen the last boat start, I went on to the first rapid, about $1\frac{1}{2}$ miles from the starting point, I found that, out of eight boats that had attempted to come up the rapid, six only had succeeded. Of the remaining two, one had run on to a rock and had a big hole knocked in her that would take some days to repair, while the other, which was an old boat, had gone entirely to pieces. Fortunately, in both cases all the stores were saved, and no men were lost. The next day, the remaining boats were got up without any further loss, and we were further fortunate in being able to obtain two more boats from Attock to replace the two we had lost. From this on to Torbela, which we reached on March 3rd, we came across no dangerous rapid, and the only difficulties were getting the coolies early enough in the morning and in finding the proper channel. As regards the first, the coolies used to leave at dusk and go to the villages round about, which were probably three or four miles off; they had orders to return by 8 a.m., but it was generally 10 a.m. before they had all arrived; and once or twice, on wet days, we were only able to muster 20 coolies in place of 120. Finding the right channel, or rather taking a wrong channel, was the other cause of delay, as sometimes, after going up a channel for two miles, you would come to a rapid with only two feet of water on it, and you had either to unload the boats and carry the stores by hand to the top of the rapid, which took most of the day, or else you had to go back and try an adjacent channel. On one occasion, when I had been looking after the boats in rear, and when we didn't get the last boat into camp till 10 p.m., I found one of the boats missing; it turned out to be the leading one. The next morning we found it in an adjacent channel. The boatmen of the second boat thought they knew better than the men in the leading boat, and the result was the loss of half a day—our channel had a rapid in it over which there was only 18 inches of water, so we had to go back and take the channel the leading boat had gone. The channels vary annually, and it by no means follows that where there was sufficient water last year there will be this. A certain amount of time is also wasted by having to cross from bank to bank, as one has first to get all the coolies on board, and then row across the stream, probably reaching the opposite bank 200 or 300 yards lower down.

At Torbela, the load that each boat carried was re-distributed for the following reasons:—

1. A certain number of boats that had previously been sent from the Cabul river to ferry some regiments over the Indus at a place a few miles lower down than Torbela would be available for us in a few days, when the regiments would have crossed.

2. A certain number of stores had come overland to Torbela from Attock, and we had also collected some more cross beams at Torbela.

So, for the advance from Torbela, each boat carried its own superstructure and that of the adjoining bay, viz., 3 trussed beams, 7 baulks, and 36 chesses. Furthermore, each boat carried a proportion of the shore bay, stores, tents, and baggage.

On March 4th, we left Torbela with 12 boats and sufficient material to bridge 150 yards of river. As my instructions were that the place where the river would require to be bridged was only about 100 yards wide, I considered we had enough for immediate use. The boats on the ferry had orders to follow us with the surplus stores as soon as the regiments had crossed.

We arrived opposite the camp at Derband on March 8th; here we were glad to find a fresh supply of 3-inch Manilla rope. Though we had started from Attock with new rope, the friction on the boulders had so worn it that, the last few days, on several occasions the towing ropes had broken coming up the rapids (in spite of having two on each boat), and though, fortunately, we lost no boat, still it is very trying for your nerves when you have only a limited supply of boats to see one of them break loose in the middle of a rapid, and go careering down. The boatmen, however, are very clever, and with their large, clumsy oars soon regain sufficient control to steer clear of rocks, etc. Coming up these rapids, we used generally to tie up two boats out of three, and mass all the men on the one towing rope.

On the 9th, we halted, and arranged with the Nawab of Amb to supply us with coolies from his district as soon as we got beyond the frontier. We moved on the 10th, and early on the 11th arrived at Bela, our most advanced post. A general advance of the force took place on the 12th; unfortunately, there was a very bad rapid just above Bela, and though we started early, it was 1 p.m. by the time six boats had got up, so I decided to push on with them, leaving Co.-Sergt.-Major Crofton with orders to get the other six boats up and camp there for the night. We arrived with the first six boats opposite the bivouac at Towara by dusk, and without any mishap, though a few men had come and fired at us from the opposite bank, which entailed putting across some of the escort, who soon dispersed them. Just as it was dark, and the men were busy cooking their food, two or three men came and fired a few shots in our direction from the opposite bank without doing any damage. Two companies of infantry, who were going on picket on the other bank, arrived about the same time, but as the opposite bank was steep and rocky, and the current strong, the only boat fit for the job was the rowing dinghy; this could only take across 15 men at a trip, and as it was pitch dark, and the landing bad, it was past 9 p.m. before we finished putting them across.

On March 13th, the boatmen that were with me had a rest while I went off with the sappers and the rowing dinghy with General Elles (now General Sir W. K. Elles, K.C.B.) to select a site for the bridge. We met Major Greenstreet, the C.R.E., a little way up the river, and a site was selected about 1½ miles above where the boats had halted the previous night. The site was very favourable in most respects, the river was barely 100 yards wide, the current about two miles an hour, and the bridge itself would be well covered. The great drawback was that the approach on the right bank would require a great deal of work. There was an alternative site for the bridge, but on measuring, it turned out to be 163 yards, with deep water on each bank, and on my return to camp I found that of the boats I had left at Bela only five had arrived; the towing rope of the sixth had got frayed by the rocks and parted, and the boat had gone on to a rock in the Bela rapid and broken up. This left us only 11 boats, which would bridge 144 yards. Four small flat-bottomed rowing boats, similar to the large boats, but only capable of taking 25 men, arrived that day from Amb, and, though of great use as ferry boats, could not be used in the bridge. Most of the stores that were on the boat that was sunk in the Bela rapid were lost; on going through the list, we discovered that the double-wheel metal travelling block was among the missing articles. This block is of regimental pattern; without it, we did not see how we were to make the flying bridge (which we knew had to be made higher up the river) work at all successfully. There was only one other block of the pattern in Bengal, and that was at Roorkee, so we wired there for a sapper to bring it up to us at once, and hoped that it might arrive before the flying bridge was required.

On March 14th, all the boats moved up to the site of the bridge with the exception of the four small Amb boats, which remained on the ferry at Marer. The coolies who had been towing the boats were sent back to their villages so soon as the boats had been taken up to the bridge site, the boatmen were put on to unload the boats, and the sappers to make the approach on the right bank, which was down a narrow gorge; a huge boulder lay in the middle of this. As time did not permit of jumping holes in it, we called in the assistance of Capt. Aylmer, who was at work on the road on the left bank, and 20lbs. of guncotton placed underneath it soon removed the obstruction, and left the gorge clear for the ramp.

On March 15th, we began to make the bridge; we had only the boatmen for this, as all the sappers were at work on the approaches, with the aid of a large infantry working party. First, we made and cast three trangar anchors; these are made as follows:—You take 24 of the ordinary palm-leaf loading nets (these have a mesh six to eight inches square) and sew them together doubled, so as to form a large net; this is doubled across, the sides AB, CD (*Plate* I., *Fig.* 5) sewn up, leaving the end AC open. You then fill the sack so formed half full of boulders, up to the line EF; the boulders must be so big that they won't go through the meshes of the net. You then sew up the half of the sack that is full, *i.e.*, along the line EF, and sew right round the sack along the line EF the centre of your cable. You then fill the other half of your sack with boulders and sew it up. This constitutes your anchor; it is made on the edge of the deck, and in the front part of the boat; when made, the boat has, of course, a great list. The boat is then taken into the required position by means of a towing rope from the bank; when in the required position, a few men easily push the anchor overboard, and with a rowing boat you can easily pick up the two ends of the cable. The bridge was constructed by "forming up," only, as the trussed beams were so heavy, only two were used, the remainder being got into position by means of a roller placed on the two already in position. By the evening, the boats were all in position and chessed with the exception of the shore bays, which had to wait for the completion of the approach on the right bank.

On March 16th, we completed the approach on the right bank, and put in that shore bay, then straightened the bridge and put in the shore bay on the left bank, racked down the chesses, put sand and grass on the bridge, and we were able that evening to report the bridge available for use. The bridge, when completed (*Plate* II.), had eight boats in it.

On March 17th, we put a large iron chain cable across from bank to bank, to assist the anchorages, and to help to stiffen the bridge; it was attached to the bow of each boat. Similarly, a 6-inch Manilla cable was fixed on either bank, and attached to the stern of each boat; stern anchorages were also put in.

Before constructing the bridge, as the gunwales of the boats were so low, in order to have a clear waterway of two feet under the trussed beams, we had to nail blocks $6'' \times 6''$ on to the gunwales of the boats; on these were nailed the gunwale pieces, $14' \times 7'' \times 7''$. The trussed beams which went from gunwale to gunwale were lashed to the gunwale pieces, and the baulks, $14' \times 7'' \times 7''$, were laid across the boats; the chesses were placed on the trussed beams and baulks. The village of Kotkai was close by, and as a certain number of houses in it had been marked for destruction, from there we obtained the extra wood we required for ribands, hand-rails, etc.

On March 19th, we moved up to Kunhar with all the sappers, five ferry boats, two large boats, and a sufficiency of boatmen. We took with us all the stores we had left with the exception of the trussed beams; these we left behind, as they were so heavy, and we thought we could manage the flying bridge without them. There is a very bad rapid just below Kunhar; up this we had to take the boats, and carry the stores overland. We were busy till the 22nd preparing materials for the flying bridge. All the baulks we had brought up had been used in the Kotkai bridge, so we had to get beams from the village of Kunhar and trim them into shape; we had an ample supply of chesses.

On the afternoon of the 22nd, we got orders to move the following day to Bakrai, three miles further up, in order to construct a flying bridge there. The same evening a sapper arrived from Roorkee with the metal travelling block, which was a great piece of good luck.

On March 23rd, moved to Bakrai; it was an easy bit of the river, with only one small rapid, and we got there by 10.30 a.m., and at once put men on to unload the stores while we selected a site for the bridge. At the site selected, the river was 150 yards wide, and the current about three miles an hour; the rapid was about 200 yards below. The right bank, at the point where we put the cable, was a perpendicular rock 40 feet high; there was, however, a fair landing 50 yards lower down, where the landing stage was. The left bank was shelving. While parties were taking across the 3-inch steel-wire cable, and making up the raft, another party was sent up to the village of Bakrai to get a couple of the longest spars they could find, in order to raise the cable on the left bank as high as possible off the water. Gunwale pieces had to be nailed on to the coamings of the boats, and then baulks nailed on these, and, lastly, the chesses nailed on to the baulks, so that it was 4 p.m. before the bridge was ready for use. However, it was not required for use that day, as the ferry boats were capable of taking all the traffic. We found when we began to work it that a back water on either bank interfered with the rapid working of the bridge; also that, on account of the shortness of the baulks, we had had to rest them on the gunwales. The bridge not being level all through frightened the animals, besides being unsightly. These two defects were remedied in a few days: the first by building out landing stages of round boulders, covered with sand and twigs; the second by getting up four of the 30-foot trussed beams from the Kotkai bridge. Baulks were then put across the boats, and a transom longitudinally on them along the centre of each boat, and the ends of the trussed beams on these transoms; short baulks were laid from this transom to the outside coaming of the boats. The whole was then chessed over with the 3-inch chesses, stout double hand rails on each side, and two slip rails at each end. The raft, when finished thus, was $40' \times 12'$, and could carry 15 mountain-battery mules with their loads on, or 45 unladen mules (*Plates* III. and IV.). When the landing jetties were complete, and the bridge in working order, a trip could be done in 10 minutes, *i.e.*, about 270 unladen mules could be crossed in an hour.

At first, we had to use the sappers to work the bridge, they having had practise in the style of thing on the canal at Roorkee; but the native boatmen soon learnt how to work it, and we then had all the sappers available for making the approaches. With some planks that we got, we made two small movable platforms, one for each bank, and when the raft came alongside, these were laid in position before the slip rails were removed, so that the animals could walk on to the landing stage.

From the information which had been collected, it seemed to be highly improbable that we should be able to take even the smallest boats we had much higher up the river on account of the rapids, so, with a view to possible operations up the river, orders were issued to us to prepare skin rafts, which could be easily taken to pieces and put together, and would be capable of ferrying over a gun or a few men. For this purpose we ordered some "surnais" from the Peshawur district, while the sappers were engaged in preparing the necessary woodwork. Before, however, we had been employed many days on this, in fact, when we had only prepared one raft, the chance of further operations up the river passed away.

On April 9th, after the main body had evacuated Palosi and crossed to the left bank, we dismantled the flying bridge and floated down to Kotkai. We halted there with orders to dismantle and remove the bridge on April 15th; by this time it was getting very hot, and the river was beginning to rise visibly. On April 15th, at 9.30 a.m., after the 37th Dogras had crossed, we commenced to dismantle the bridge; this was completed and all stores ready packed by 12.30. The boats we were able to take down fairly empty, as all the heavy trussed beams and most of the chesses were made into rafts and floated down separately. We reached Derband at 3 p.m. the same day, and we halted there for the night. On April 16th, we started at 7 a.m., and commenced to row down the river, and by dusk had arrived about 10 miles above Attock, and halted there for the night to let the men cook their food, etc. We started early the next morning, and arrived at Khairabad by 10 a.m.; the boats had to be let down the last rapid, the one in front of Attock, by hand. The next few days were occupied in storing at Khairabad the articles belonging to the temporary boat bridge, and in returning other stores that had been borrowed from the Punjab Government to the boat bridges at Nowshera and Kushalgurh. The pontoon section then returned to Roorkee by rail.

G OPERATIONS. HAZ

PLATE I.

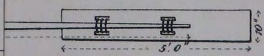
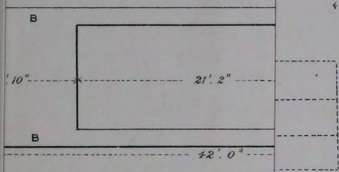


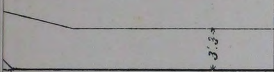
Fig. 2.

COUNTRY BOAT USED FOR

Plan.



Section.



These boats had square bows
were flat bottomed. _ Both e

VELLING BLOCK.

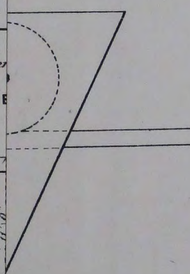
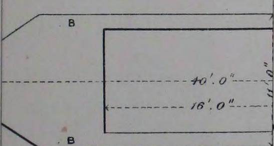


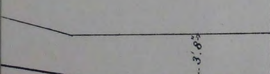
Fig. 3.

RY BOAT USED FOR FLYING

Plan.



Section.



These boats had pointed bows a
were flat bottomed. _ Both end

PAPER V.

MULTAN CHURCH ROOF.

BY LIEUT. G. C. KEMP, R.E.

As the roof of the New Multan Church is an interesting one, I propose to give a short description of it, and send an elevation of a truss used in the nave of the Church.

The truss was designed by Colonel Manderson, R.E., and is, I believe, practically unique, although similar ones with smaller spans are being designed for a church in one of the stations in the Simla Hills.

The ribs are built up entirely of planks, the outer layers being of pitch and Oregon pine, procured from the North-Western Railway, and which had been used as scaffolding for the bridge over the Chenah at Shea Shah.

The inner layers, as well as purlins, etc., are of deodar, procured from the Cheog Forest beyond Simla.

Chancel Trusses (*Plate* I., *Fig.* 4).—Width of room, 22 feet 6 inches.

Wood Used.—For principal rafters, deodar, 6″ × 6″. For struts, *a*, deodar. For wall-pieces, *b*, deodar. Ribs, mostly pitch-pine wood; some of the shorter pieces being of deodar.

Construction of Ribs.—Each rib consists of five layers of planks, 6 inches wide, 1½ inches thick, and about 22 feet 3 inches long.

The planks were steamed for four hours in a long wooden box, to which steam was admitted from the portable engine used for grinding mortar on the work. The planks for one rib only were steamed at a time.

They were moved, singly, from the steaming-box to a wooden platform (*Plate* II., *Figs.* 1 and 2) on which a "ferma" of the correct curve was formed with Keekur wood chocks, *c c*, 12 inches long, 6 inches wide, 6 inches high, arranged as in the sketch.

The lower or springing end of the plank having been wedged up, it was bent into the ferma by coolies, a couple of carpenters following up with wedges, *d d*, to keep the plank in position. Battens about 18 inches long, 2 inches wide, and 1½ inches deep were laid cross-wise under the lower edges of the plank at intervals of about 3 feet, and screwed to the planking of the platform. This admitted of the cramp shown in *Plate* II., *Fig.* 2, being used with greater advantage.

This cramp was applied when the second and subsequent layers of planks were laid, and was found most useful for tightening up the planks at those parts where wedges could not be introduced and where butt-joints occurred in the rib (*Plate* II., *Fig.* 3).

Plate II., *Fig.* 4, shows the general arrangement of screwing planks together. For these trusses 2½-inch screws, No. 18, were used for the first and second layers of planks, and 3-inch screws for subsequent layers, so as to obtain a better grip.

A margin of about 1½ inches was left along the edges of planks, that is, no screws were driven nearer than 1½ inches from the edge, to allow for chamfering.

Full length planks were used as far as they were available. For the upper and lower layers of each rib, planks of the full length were obligatory, but short lengths were introduced in the intermediate layers, arranged as shown in *Plate* I., *Fig.* 1. Thus each joint occurred, as nearly as possible, mid-way between two contiguous bolts, and only one cross-joint occurs at any cross-section of the rib.

Plate II., *Figs.* 5 and 6, shows the manner of securing the joint where the half-trusses at the apex end of chancel abut against the full truss. This arrangement has effectually prevented any upward tendency in the ribs of the half-trusses.

The ¼-inch iron cover shown in *Fig.* 6 has been covered with a 1¾-inch plank of the same shape as the plate. An ornamental final will be probably added.

The chancel trusses took on an average about five days to build for each full truss, and three days for each half-truss.

Each rib usually took 12 maunds of firewood in steaming, but 15 maunds were often used when the weather was rainy (in December, 1890).

Several pitch-pine planks failed completely in bending.

When the first truss was removed from the ferma on the wooden platform, the ribs kicked out three inches beyond the span to which they were built. Tie-rods were subsequently used to keep the feet of the ribs in position until the trusses were hoisted, when they were removed. The four full trusses were hoisted by contract for R40.

The four half-trusses were hoisted departmentally for about R4 each.

It was found necessary to "truss" the half-trusses as shown in *Plate* II., *Fig.* 7, before they could be hoisted, owing to the strong tendency of the rib to straighten out. The tie-rod and strut could not be removed until each piece was firmly fixed in position.

The nuts and washers of the bolts through the ribs have been covered with deodar bosses (*Plate* II., *Fig.* 8), and the under-side of the rib finished off with a chamfer as shown in *Plate* II., *Fig.* 9.

Nave Roof.—$38\frac{1}{4}$-foot trusses (*Plate* I., *Fig.* 1). Span of room, 38 feet 3 inches. Principal rafters, deodar from Simla, 8″ × 8″. Struts, 12″ × 8″. Ribs, pitch-pine wood and deodar. Section of rib, 8″ × 10″. Ribs composed of five layers of planks, 8 inches wide, 2 inches thick. Upper and lower layer of each rib consisted of one full length plank (39 feet) of pitch-pine wood.

Intermediate planks were mostly of deodar, locally purchased, and were arranged to break joint.

Bending and steaming arrangements same as for chancel trusses except that the planks were steamed for six hours instead of four.

General arrangement of screws as in *Plate* II., *Fig.* 10. No. 17 and No. 18 screws, three inches long, were used, care being taken that no screws were driven where a bolt was to come. The position of each bolt was marked on the platform so that the carpenters had no difficulty in guarding against driving screws where they might cause obstruction when the truss was being framed together.

The first of these trusses took nearly 17 days to complete.

The bending of the planks took two days; generally five carpenters did the actual bending and screwing up of each rib.

Fifty maunds firewood were used in steaming the planks of the first truss.

The remaining trusses averaged about 40 maunds firewood for steaming, and took from six to seven days to complete and hoist into position.

The ninth and last big truss was hoisted on the evening of the fourth day from commencement of steaming planks. Five carpenters working overtime each day completed this truss ready for hoisting.

The hoisting was tedious and difficult. At first two derricks were used, but as the trusses had necessarily to be raised diagonally to the height of 27 feet 6 inches, then turned round and lowered on to the pillars as shown by dotted lines (*Plate* II., *Fig.* 11). This condition practically limited the number of derricks to one, fixed in the centre of the room. One derrick, therefore, was used for the remaining trusses. A teak wood beam, $8'' \times 8''$, was fitted to the under-sides of the truss rib, below the tangential points of the principal rafters, the ends of this beam being kept in position by means of two pairs of iron straps $3'' \times \frac{1}{2}''$, bolted together by $\frac{7}{8}$-inch bolts. The lifting rope was adjusted at the middle of this beam and the arrangement worked successfully.

Manilla rope was used for hoisting the trusses.

Bosses, same pattern as on the chancel trusses, were fixed on the under-side of the truss ribs, following the arrangement of the bolts through the rib (*Plate* II., *Fig.* 12).

The work of the large nave ribs was done in the hot weather, April, May, June and July, 1891, and we had to work chiefly in the early morning to prevent the planks drying too soon. As it was, a good many gave way during the bending process.

I have not attempted to describe anything beyond the mere making and hoisting of the trusses, as far too much space would be taken up.

I was most admirably assisted by Sergt. Boyd, Overseer, M.W.D., who managed to overcome all difficulties (and these were a good many) with great ingenuity ; and by a very clever Mistri Alla Ditta.

The roof as it now stands, with no tie-rods, looks very striking, and is not an expensive one.

ROOF OF … PLATE I.

EL ROOF.

FT. SPAN

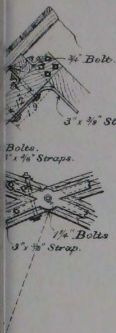


Fig. 4.

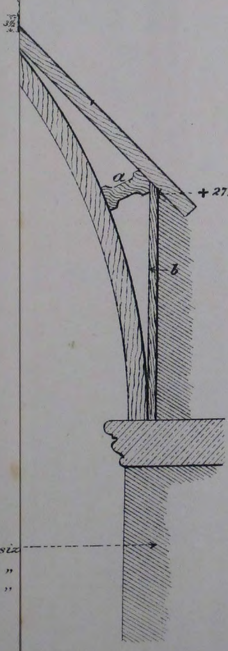


Fig. 1. Scale, 1/60 full siz
" 2. " 1/30 " "
" 3. " 1/4 " "

PAPER VI.

BIZERTA.

By Col. J. R. Hogg, R.E.

The development of this remarkable port upon the north African coast, some forty miles west of the city of Tunis, has doubtless been a matter of curiosity to officers of the Corps when, from time to time, it has been brought to notice by the public press. The term "remarkable" is certainly far from extravagant; indeed, it might more truly apply to the indifference apparently felt by the governments of Europe for several years now past as to what may be in contemplation at that particular point of the Mediterranean.

The world coast-lines may be studiously scanned without discovery of many such features of advantage as this port of Bizerta presents upon the main high-road side of sea commerce between Britain and the East.

Land upheaval, and the silting up of its ancient narrow inlet from the sea, have naturally converted this splendid harbour, of an age bearing no record but fable accepted as such, into a deep sea lake land-locked against every modern ship. A rough idea of the proportions of that lake may be thus expressed, viz. :—Within its shelving-shore belt of shallower water there lies a roughly rounded off equilateral triangle of seven miles side, one apex pointing south, with nowhere less than 30 feet of water, and the best possible anchorage stuff as a bottom floor over the whole area.

It is quite needless here even to touch upon the reasons which for so many years have restrained the government mainly concerned from ordering any works for the development of this unique port; it is sufficient to say that little more than one year from their fair start has now exhibited these works as virtually an accomplished fact, and that their completion within two years more, perhaps within one, is certain; indeed, any engineer would undertake the solution of the real problem in four months.

That main problem is the passage of the heaviest ships of war now afloat, or in contemplation, from the open Mediterranean into this superb sea basin; it is being settled by the dredging of a ship canal about 2,000 yards long, 100 yards in clear width between foot of slopes, and 30 feet deep.

This work is being carried on with every mark of economical engineering skill by the concessionaires, who are in contract with the Regency of Tunis; the mere fact that payment for it takes the form, not of money down, but of property rights of established and rapidly increasing value, is a spur that the contractor in all countries has the deepest respect for.

External to this canal cutting, for the two-fold purpose of protecting it from longshore drift of silt and for anchorage of a few vessels, safe perhaps even against battering guns, the two breakwater arms in the project will doubtless answer well; the system of *pierre perdue*, carrying terrace and parapet of block concrete, will have to stand no ocean shock upon the coast of Tunis. These breakwater arms will be each 1,100 mètres long, with 400 mètres central opening; the western one is two-thirds formed from quarries some two miles west of the town, the eastern one will now shortly be commenced from quarries in a locality equally suitable for its easy execution.

For protection against the operations of war upon this harbour entrance, as against raid, or against what is termed insult, the present intentions of the government concerned, so far as they are known, are admirably sensible and wisely modest. Upon the sketch which illustrates this paper, taken from the French W.D. survey sheet, of $\frac{1}{50000}$-scale, the points marked A and B are each intended for the emplacement upon high barbette of two or three armour-piercing guns, for the present those of 25-c.m. calibre. At C a small work, as wing battery to B, is intended for lighter and quicker, right and left, longshore fire against attempted landings.

The ground is not yet scratched for these defensive arrangements, nor is there any reliable evidence of the existence upon the north African coast of any ordnance material intended for them. The sites at A, B and C, understood to be now intended for the emplacement of guns, were not chosen from a varied stock of alternatives; they are signally indicated by natural configuration as the very best conceivable for the purpose. Racer beds can be planted at about 200 feet above sea level, with parapet cover easily avoiding sky line demarcation, and also easy to protect against capture by surprise or destruction by any systematic attack of short duration.

A plan exists in London, probably not furnished by the French War Office, describing, in project, a girdle of forts upon a radius of some 5,000 yards to encircle the land locality of the port, but, on the spot, no evidence of the truth of such an idea is extant.

Perhaps its supposition has arisen in the minds of wayfarers noticing the contractors' line of rail, etc., working from quarries in the hill mass of Djebel Kebr for the formation of the western breakwater arm.

Indeed, as was aptly remarked by a distinguished R.E. officer who visited Bizerta several years ago, it may well be doubted whether, at any early date, its port may seriously menace any Power that may be at war with its present owners; for, as he considered, this lovely-looking inland manœuvring basin may prove a death trap, not merely to any swarm of marauding torpedo craft, but possibly to the main battle fleet of a Power that does not hold the mastery of the sea. The power that is in that desirable position, and must either maintain it or perish, should, if necessary, "cork up Bizerta," without fooling away time over the operation or delaying other and heavier business.

At the same time, the acquisition of Bizerta by the Power holding that sea command may, some day, be viewed as a matter worth thinking over; the wise prophet will hold his tongue, but keep an eye open to the really charming surroundings of Bizerta.

Of such military force as may, later on, appear on the scene, the present forerunners (mainly for the display of civil power) consist of a half battalion of Zouaves in the new brick cantonment west of the old Arab walls of the town, a company of artillery with a few field guns in the old Fort d'Espagne, a small detachment of Sappers in the Khasba, and a small horsing remount depôt.

A topographical feature of the near locality of the port is soon noticed, though it is not striking on near approach from the offing; this is the shelter against direct fire from the sea, or, at all events, the visual screen afforded by the shore-line of isthmus to the north-eastern angle of the lake. It is, however, far from likely that this would be found worth taking advantage of for the formation at that point of any fixed establishment for the coaling of vessels, though doubtless useful for certain temporary purposes under a state of war.

PAPER VII.

SOME METHODS OF ENGINEERING ECONOMY IN DESIGN.

By Captain G. K. Scott-Moncrieff, R.E.

It may be said that engineering economy is a wide subject, that it is practically synonymous with the whole art of construction, and that, therefore, to attempt to treat it in one or two essays is as ridiculous as it is unnecessary. Or it may be said that the whole question is one of common sense, and, therefore, that nothing can be said about it which any man of ordinary intelligence could not find out for himself. To these objections we reply that a man may be a successful engineer, and yet be most extravagant, either from want of care, or, what is more probable, from the neglect of a few guiding principles. Again, though the matter is doubtless one of common sense, still the fact that the absence of economy in public buildings stares us everywhere in the face seems to indicate that the requisite sense is not by any means common.

The greatest engineer, like the greatest general, is the man who makes fewest blunders; and just as in our studies of war we examine and learn from the mistakes of military leaders, so in the arts of peace we may learn how to avoid mistakes by examining the palpable errors of others. In citing examples to be avoided, we do so in no spirit of fault-finding criticism. Pressure of time and other circumstances have often been the cause of engineers' blunders, and we endeavour to note these blunders for the benefit of ourselves and of the public, without passing any criticism on the authors.

Before proceeding to discuss the various ways in which engineering economy may be practised, it is as well to lay down what it does *not* mean. It does not mean an absence, from financial reasons, of all ornament. "As ugly as a barrack" has become almost a proverbial saying, because of the false economy in this respect of the engineers of the past. Modern engineers are doing something to remove this stigma, for certainly some modern barracks compare most favourably in appearance with other public buildings. Ornament in the right place and of the right sort is not extravagance, though we do not expect to find it in the middle of a railway tunnel, for instance, or in any other place where the educated eye will not be offended by its absence. Again, engineering economy does not mean solely and only complying with financial regulations, and always working within sanctioned estimates. It is quite possible to commit the greatest extravagant blunders, and yet present an office record of perfect correctness. It often happens, however, that the engineer who is careless about the economy of his work is careless about the exactness of his expenditure, and while both are faults strongly to be condemned, there can be no doubt that of the two carelessness about the work is by far the worse. An engineer who spends his whole time on his work and leaves his office to his clerks will probably cause much annoyance and trouble to the financial authorities, and be much to blame for that trouble, but the engineer who spends his time in his office and leaves his work to the contractor will cause annoyance, trouble and expense to future generations by reason of the bad work that will certainly follow.

The question of engineering economy is one which is interesting to all engineers, and ought to be specially interesting to us R.E.'s, because we derive no pecuniary benefit direct or indirect from the money which we save on public works.* We R.E. officers are entrusted with large sums of public money, and our pay and allowances are not directly affected by the way in which we discharge our trust. It should, therefore, be a point of honour that to the utmost of our ability we should show ourselves worthy of the honourable *rôle* which we have had committed to us, and use our endeavour to bring to bear on the subject the special training which we have had. More-

* An architect or civil engineer who does good and cheap work will probably get more employment. It is, therefore, to his interest to do it economically.

over, when an officer has been able, by means of his common sense or his technical knowledge, to save public money on the construction of a work which he has been able to bring to a sound state of completion, it is a very sincere cause of satisfaction to himself. Anything which will tend to bring about such a result is worthy of our consideration. If the present paper should give rise to discussion and produce the opinion of experienced officers, it will have amply fulfilled its object.

Our ultimate aim is to show how public money may be saved. But engineering economy does not always consist in the saving of money. An engineer in the field, with a limited amount of labour, tools or material, employing each or all to the greatest possible advantage, is practising public economy just as if he were paying for it all. As it is one object of our field-work practice to show how the above may be done, it will be seen that the principles of engineering economy have an important military bearing in some of their aspects.

Economy may be attained in the following main divisions:—

1. Economy in design.
2. Economy in specification.
3. Economy in execution.
4. Economy in accounts.

Of these four, it is only proposed to consider economy in *design*. Want of space forbids the consideration of the other divisions. The examples which it is proposed to quote will be taken from the two main branches of engineering which we as a Corps have to deal with, viz., barrack construction and road or railway engineering.

Economy in design is by far the most important of all the divisions of the subject to us officers, because it is on this particular point that an officer's responsibility is most centred. The specification may very legitimately be the work of a surveyor, the execution may be largely in the hands of contractor, foremen of works, etc., the accounts may be kept straight by a clerk, but the design of a work is, or should be, the work of an officer and no other person. Extravagance there means extravagance more or less all through, and there can be no shifting of the blame on to the shoulders of others. It is reasonable, therefore, that we should consider this subject carefully.

In so doing, however, it is not necessary to touch upon indirect extravagance of design where works are technically correct, but have an arrangement tending to produce waste of public money.

For instance, there are horse artillery barracks where the stables are so arranged that the horses get a maximum of foul air with a minimum of light, the result being sickness, waste, and inefficiency. This is an indirect extravagance of design, for the buildings themselves are not faulty.

An engineering design is economical when it *thoroughly* fulfils the required conditions without using an unnecessary amount of any material.

Let us first take the case of a building—barrack or other house.

The first thing to be done is to design the foundations. Everybody knows that these have to be taken down to solid ground which has lain undisturbed for ages, and is free from springs, shifting sand, and any other unsoundness. The state of the ground at the proposed site is generally known to the designer, and he arranges his depth accordingly. If he does not know what the ground is like, he ought certainly to have a trial pit dug, otherwise his design will be extravagant in some way. However, supposing he does know the soil and the depth to which he intends to go—four feet being the usual allowance in this country so as to be clear of the effects of frost—the next point is what width and what thickness of concrete should be put in? As regards width, it is very easy to calculate the maximum weight of any small cross section, say one foot long, of the proposed building. If this weight on the foundations does not exceed one ton to the square foot* the concrete is wide enough, but in most places the concrete is so wide that the weight per square foot is often only half-a-ton. The concrete may, therefore, be reduced in width. There is no economy in having it very wide. Then, as regards thickness, six inches is the least that can conveniently be laid, and foundations are never less than that. A common plan is to give six inches of thickness for every 10 feet of height. This is, of course, a very rough rule, but it is good enough for all practical purposes, and with ordinary good concrete is near enough to the calculated limit. The subject has been occupying a good deal of attention lately in professional papers, and thorough investigation made into the whole question. Often very much greater thickness of concrete than the above is given to save brickwork, which is more expensive than concrete.

* In all ordinary stiff soils. On rocky soil it may be three tons, and in loam ·8 tons, but, generally speaking, one ton is good enough. This is less than Rankine gives.

The next point to be considered is the walls. As a rule, I venture to think these are designed quite light enough at home, in fact, if anything, too light. In a dwelling house there is no economy in a double half-brick hollow wall. The house must be cold, and often the discomfort caused in this way causes the whole of the house, however good, to be considered bad. The walls should be thick enough to be warm. Another point to be remembered is that light walls tend to decrease the general stiffness of the whole building, and, especially if the roofs are heavy, tend to produce cracks in partitions and sagging in floors. A very extravagant and most objectionable habit is to build soil and other pipes into walls. The result is that if there is any stoppage in the pipes, the walls have to be pulled down, as they are generally saturated, and in any case they must be removed to get at the pipe. At the cavalry barracks at a certain station, the night urinals were situated above the cook-houses, the soil-pipe from the former leading through and down the wall of the latter—a most revolting arrangement, which is now remedied. The result of this faulty arrangement is quite obvious.

With regard to floors, no floor that is exposed to the action of rain should be of wood. In the verandahs of some barracks at home, the floors are made of 3-inch deal planks. The result is that after a while rain makes them soft and rotten, and they get worn in parts where the traffic is great. A regular sum of money every year, some £200 or so, is allotted for repairs, and as this does not go very far*, it is generally spent on renewing patches. These patches are of the original 3-inch thickness, while the old floor is perhaps only 2-inch, being worn away. The result is that the patches become pitfalls, for the unwary and the belated soldier, coming home in the dark, tumbles over them, so that his feelings and language are possibly to be imagined, but had better not be described. Another evil of these wooden floors is that they receive all the washings-out of the barrack-rooms, for in spite of all the regulations on the subject, the soldier will clean out his barrack-room by swilling water over it. The dirty water finds its way over the wooden verandah floor, and trickles over the edges, disfiguring all the ironwork of pillars and girders below.

It has been proposed to put concrete floors in one of these barracks as an experiment, and to make a ledge of iron at the end to catch the water, leading it down below in regular down pipes.

* And does not admit of doing a whole block at a time.

These wooden floors have been most expensive, and if they had been originally made of concrete the initial cost might have been more, but the ultimate saving would have been very great.

Inside a barrack, I can see no reason why floors should not be made like the deck of a ship, with caulked joints. I believe this subject is under the consideration of the War Office authorities at present. A floor was made at the Curragh a few years ago (under no special orders from the War Office, however) of this description, which has answered very well. It wears much better than the ordinary rebated or grooved and tongued floor, and "Tommy Atkins" can use water over it to his heart's content.

Now we come to roofs, and here more than in any other part of public buildings is extravagance most noticeable. The most ordinary form of roof truss which we have to deal with is the king post, and the usual form that that truss takes is shown in *Fig.* 1. Here it will be observed that the principal rafters are very light, that the struts meet the king post on a shoulder above the tie beam, and that the tie beam is very heavy. All this is a most extravagant arrangement. To prove this assertion it is necessary to go a little into theory. The ratio of the strain on the principal to that on the tie beam is in the proportion of cosec θ to cot θ (θ being the angle of roof). As the cosec of an angle is always greater than its cotangent, it follows that the strain on the principal is greater than that on the tie beam. Therefore, the principal ought to be the larger timber. But it may be said the strain on the principal is compression, and that on the tie beam is tension. That only makes matters worse, however, because the resistance of timber to crushing is very much less than the resistance to tension. To recapitulate :—The principal has to bear a heavier strain than the tie beam, and has less power of resistance, hence it ought to be much larger instead of much smaller than the tie beam. Hence, if the principal is right, the tie beam must be wrong, and extravagantly so.

I have said nothing about a ceiling, however, and as the tie beam has to bear the weight of the ceiling, and, moreover, must not have the least deflection, so as to keep the ceiling from cracking, it is necessary to consider what amount of extra depth should be given to the tie beam. General Wray has, however, proved in his book that a very little extra depth given to a tie beam will suffice to give it stiffness, and certainly not the heavy timber usually constructed. Another extravagance in this arrangement of a king post truss is in the king post. Owing to the shoulders at top and bottom, it is necessary to take a beam of a much larger scantling than is necessary for the effective work. Thus, if the calculated size of the post be 4″ × 4″ it is generally necessary to take 7″ × 4″ piece of timber and cut it to the required shape, or, in other words, you waste nearly half of it. It may not cost much in one truss, but if you have to build several blocks of barracks, each with several trusses, it means money.

The faultiness of this usual form of king post truss has long been recognized in India, and it is not used now in the Military Works Department. Another form is adopted, in which principal and tie beam are the same size, the king post is double and passes outside the tie beam, secured by a strap and wedges (*Fig.* 2).*

A still better form is one which I think is in the roof of the Curragh gymnasium, with an iron king rod, terminating in a shoe and a double tie beam, passing outside the foot of the principal (*Fig.* 3).

I have gone at some length into this particular form of truss, because it is the most common, but the broad rules which apply here apply, of course, equally to all trusses.

Then, with regard to the upper parts of a roof—the purlins and common rafters—how often we see the same neglect of simple principles. We all know that the strength of a rectangular beam varies as bd^2, while the price varies as bd. Yet, though a 5″ × 4″ rafter is more expensive and less strong than a 6″ × 3″, how often we see it, or something like it, put in a roof. There are limits, of course, to the ratio of b to d for practical reasons; the best rule, I think, is that $d = 2b$, where both strength and stiffness are desired.

All this means public money gone from want of economy of design, and attention to very simple principles.

Now, it only requires the most elementary knowledge of mathematics to prevent all this. There are formulæ dealing with the subject in all the pocket-books, and five minutes' work will often solve the whole of the question of dimensions in a roof. Officers very often shy at this, because they say they are not good enough at mathematics, whereas really the knowledge required is so simple that men with hardly any mathematical knowledge can work out the formulæ with very good results. The pocket-books generally give tables of dimensions of beams and trusses for ordinary cases; but it must be remembered that these tables do not profess to solve all the

* Indian barracks, however, have rarely ceilings.

cases that arise, and as the conditions of roofs vary immensely, it is far better to solve each problem that arises on its own merits and use the tables as a guide in comparing the results than follow blindly the results given there, which may have been based on totally different data.

In Indian barracks one is struck with the excessive use made of iron straps and bolts in roof construction. In a verandah with a heavy roof, everything is bolted and strapped in a most lavish way. The pillars are bolted to the bases below and strapped to the bressummers above (see *Figs.* 4 and 5), and each rafter is bolted and strapped to the bressummer. This is overdoing it, I think, though it is a fault on the right side. But it does not do to neglect these fastenings altogether. A case in point occurred some little time ago. In one of the midland counties a rifle range was being made, and a shed was required, in a somewhat exposed position, for sheltering the men in wet weather. The military foreman of works sent a plan of a timber shed built on dwarf walls, but with no iron bolts anchoring the timber to the brickwork. The division officer sent this to the C.R.E., stating that, in his opinion, anchor bolts were necessary, and that it would be dangerous without them. The C.R.E. referred it to the district surveyor, who said that he considered the shed was safe enough without them. The C.R.E. ordered the construction accordingly. The result was that the shed was blown down, which was, perhaps, satisfactory to the division officer, but expensive to the public.

Good carpentry will often solve the question of joints in a roof, or floor, or staircase, and it is only where an engineer cannot count upon skilled workmen that he must take the precaution of remedying bad joints with external fastenings.

Roof coverings of an economical description are often a very difficult question to settle. At home we go in for slates nearly everywhere, irrespective of the building to be covered. Now slates are undoubtedly the best covering for a dwelling house in a northern climate; tiles get saturated with damp and let in snow, unless the roof is of steep pitch; iron sheeting is hot and noisy. But slates suffer terribly in a gale of wind. I have seen in one barrack division, where there were literally some acres of slate roofs, hundreds of pounds' worth of damage in a single night. Many of these buildings were storehouses, which might have been roofed more cheaply and effectively with galvanized iron, practically proof against any wind so far as stripping and leakage is concerned. Again, no roof covering is economical that requires periodical treatment in the way of tarring or painting. Thus the hut roofs in some of our large encampments require tarring every few years. This is expensive in itself, and the accumulated layers of tar become, in time, very thick and cause dangerous sagging in the timbers below.

In the plain stations in India, tiles are much used and are admirably adapted for the purpose required. But they would be quite unsuitable for England, on account of snow. An English barrack is a very much more complicated building than an Indian one. In the latter there are no drains, no water pipes, no gas, no complicated ventilators. Except in the hill stations, there is no need to arrange for warming the buildings, as that is generally done effectually by the sun. Hence an engineer's attention can be wholly paid to the broad details of construction, which I have endeavoured to point out above, which are too often overlooked in our home designs.

The above points are a few of the different methods whereby economy of design can be attained in barracks, but there are many others of equal, if not greater, importance, which call for economy. All sanitary questions, plumber's work of all sorts, may or may not be extravagantly dealt with in design. I purposely do not touch upon these, as they have attracted much attention of late, and have been exhaustively treated by more expert writers than myself.

In roads and railways the connection between survey and design is very close. It must always be remembered that in these cases the economy does not consist in saving money in the initial cost so much as in producing a design which will enable the line of rail to be worked with economy, or the road to require a minimum of repair while admitting a maximum of traffic. The case of a railway line is not always the same as that of a road. In the former case straightness should be aimed at, with as much level running as possible; but this does not always follow in the latter case. I heard of a case where a road had to be made between two points separated by the shoulder of a hill. It would have been easy to have made a road round the hill, and a road did exist along that line which, with a little repair, would have sufficed. The engineer in charge thought it would be better to take the road straight through in a cutting. This was done at a great expense. Springs were tapped in so doing which kept the road always muddy. Snow lay there in winter. The wind down the cutting was very disagreeable at times. The work was a mistake. But if it had been a railway there is no doubt that the procedure would have been quite sound.

An engineer is apt to save earthwork in the design of a line at the expense of easy gradients. It must be borne in mind that the haulage power of a locomotive decreases very rapidly with an increase of grade; thus the haulage on a 1 in 50 incline is only about one-half of 1 in 100. So it is a very false economy to spare a cutting or bank for the sake of expense when, with no very great trouble, an easier gradient may be secured. Of course, there are limits to the reasonable amount of earthwork to be carried out; yet it is an error on the right side to increase earthwork and save inclines. So also a line with many curves means very frequent rail renewals and wear and tear of rolling stock.

Hence to save a series of curves or heavy gradients it may even be economical in some places to tunnel, although tunnels are expensive in themselves. But of all expensive tunnels the worst are those which are in dangerous rock, and from a false economy have not been lined at first. The most dangerous work I have ever had to carry out was the removal of a great loose rock at the crown of an unlined tunnel inside. One could not help wishing that the man who made the tunnel in the first instance had been obliged to complete his work.

It is never an economy to stint drainage openings in the earthwork of a road or railway. If neither time nor necessary data are available for calculating the waterway, it is always better to make it too large than too small. The disasters consequent on too small waterway are common and costly, whereas one rarely hears of money being thrown away on too large works. A case occurred where a celebrated engineer thought that a railway embankment would act as a sort of reservoir dam, and that all that was necessary would be to make a little 10-foot opening at one side to act as an overflow outlet when the water was ponded up by the embankment. The line was made accordingly. Presently a flood came, and made a breach straight through the middle of the bank, leaving the rails and sleepers in a graceful festoon above. A large and expensive culvert had to be run up quickly to restore traffic at more costly price than would have followed had the work been built in the first instance.

It is often difficult to judge whether a masonry bridge, or a culvert, or a girder bridge is the cheapest form of spanning a drainage or other opening. In certain cases the solution of the question is easy, *i.e.*, when the site admits of only one form. Even when it is clear that girder bridges are the only way, the question of the best design is not always clear. Not that the actual girder itself need ever trouble one. No R.E. officer would ever have to design a railway girder, they are always done by the manufacturers, on a given span, etc., being notified. But the difficulty is whether to have a few large girders or many small ones; and to solve this satisfactorily one has to consider the building material and the labour available for construction of piers and abutments, the nature of the foundation, the facility for getting girders to the site of the work, and for erecting them. It is all very well to say that the economical rule is when the cost of the girders is equal to the cost of the piers, because, practically, in many cases, one of these is an indeterminate quantity. Foundations vary so much that with every precaution an engineer may find the cost of his piers doubled by unseen work below ground. Floods may cause masonry to be ruined before it is set, or, on the other hand, erecting plant for girders to be wholly destroyed.

A drainage opening in a very high bank presents sometimes a perplexing problem whether to cross by means of a culvert with heavy earthwork (as in *Fig.* 6), or have a small girder bridge with very high wing walls (as in *Fig.* 7), or have one large central girder with smaller ones at the ends (as in *Fig.* 8), or to have a masonry viaduct, dispensing with girders altogether (*Fig.* 9). It is generally a question of materials at the spot.

Fig. 10 represents a culvert which may serve as an example of an economical design in respect of utilizing materials on the spot. The arch is 22 feet span, semi-circular, and the foundations are bound together by a concrete invert. This work was built in a country where roads were few, and skilled labour rare. There was good stone at a quarry some three miles from the site of the works, but the only lime was a very poor stone lime, cement being too costly to be thought of. The concrete made of this lime and brickdust was carefully tested in experimental arches with good results, and these induced the engineer to design the culvert with the bold expedient of a 22 feet span of concrete. Of course, the concrete had to be most carefully mixed, laid, and examined, but the result justified the expectations. Dotted lines show the way in which the layers of concrete were laid.

As regards the dimensions of masonry piers in railway bridges, it was customary on the Indian railways to make the length of pier, exclusive of cutwaters, from four feet to six feet greater than the outside dimensions of the girders, according to the span. Then if the pier was more than 20 feet high, an offset of one foot was always given all the way round for each 20 feet. These dimensions do not appear extravagant, and yet in the approaches to the Forth Bridge there is no increase of length or width for height beyond an almost imperceptible batter, which looks the more insecure in that the trains run on the top boom of the girder, not as in India, on the bottom. The length of these piers is, I think, only two feet more than the outside of the girders. I pointed this out to one of the engineers of that great work who was showing me over it some years ago, saying that it seemed risky. He said, however, that the matter had been very carefully considered. The result has certainly justified this bold treatment.

L'audace toujours l'audace is a good military rule, and is an excellent principle in engineering when based upon sound scientific deduction, otherwise it is folly. Whether in barracks or in bridges or tunnels, an engineer must always remember that he is responsible for the lives and safety of his fellow men, and carelessness is worse than folly—it is almost crime. The following case will illustrate what is meant. An engineer built a small rail opening across a tiny water-course, and apparently considering that it was not worth wasting much money over, he neglected the rule to take his foundation down to solid earth. He put instead six inches of concrete underground and no more, this apology for a foundation resting on the loose gravel and sand of the stream. A heavy flood one night scoured under these foundations, and although to outward appearance the structure was all right, in reality it was resting on water, and was hanging to the rails above. Next morning a heavy goods train came up the line, drawn by two large locomotives. The result was, of course, a most appalling accident. The lives of the unfortunate men who were killed were lost entirely through the neglect of most elementary rules of construction.

With this I conclude a very cursory examination of a most important subject. Want of space forbids the consideration of the questions of economy in materials, in execution of the work, and in settling up for its payment. Possibly the suggestion of these topics may induce some officers of experience to publish their views and practice, and thus add to the knowledge of the Corps in a science which is essentially experimental.

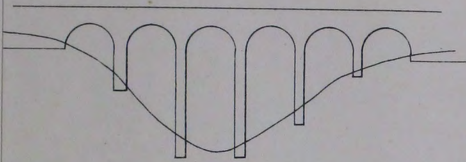


Fig. 9.

Crossing same opening with masonry viaduct.
Heavy masonry.
Difficult centering.
No earthwork.
No ironwork.

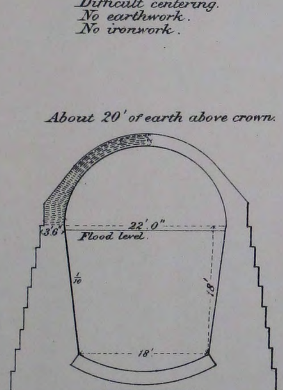


Fig. 10.

Cross section of masonry culvert with 22' concrete arch (semicircular).

Length of culvert about 120'
The dotted lines show the layers of concrete in arch.
Scale, 30' = 1"

PAPER VIII.

GRAPHIC SOLUTION FOR EQUATIONS OF THE SECOND, THIRD AND FOURTH POWERS.

(*Translated with permission by*

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From a Paper in the "Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens," by Lieut. Julius Mandl, of the Imperial Austrian Engineers).

IN order to avoid the use of logarithmic tables and the necessity of obtaining the second and third roots in the solution of equations of the third and fourth power, the accompanying table was constructed for solutions in which greater exactness was not required than the first two or three figures.

The mathematical reader will be in a position to determine, from the following considerations, the number of the complex (imaginary) roots and the sign of the existing real roots which can result from an equation of the second, third, or fourth power.

In order to understand the reasoning on which the table is founded, we must begin with equations of the second power.

I.—EQUATIONS OF THE SECOND POWER.

An equation of the second power with roots x_1 and x_2 has the form

$$x^2 + Ax + B = 0 \quad \ldots\ldots (1),$$

in which

$$x_1 + x_2 = -A \quad \ldots\ldots (2),$$

$$x_1 x_2 = B \quad \ldots\ldots (3).$$

Using x_1 as the abscissa, and x_2 as the ordinate in a rectangular co-ordinate system, then (2) represents the equation to a straight line, and (3) the equation to the rectangular hyperbola referred to the asymptotes. The intersections of these two lines give points whose abscissæ furnish one root, and whose ordinates furnish the other of the quadratic equation (1).

To simplify this construction, the accompanying table was compiled. To use it, a piece of transparent gelatine is required, on which the following lines must be drawn (taking them off the table itself). The parabola P, its axis *ab*, the tangent at the vertex DC, and the straight line AB.

In the table, 1cm. was taken as unity for the values of the co-ordinates. Hence the table is divided and numbered on the axes from 0 to + 10, and 0 to − 10. These squares are again sub-divided into tenths; thus tenths of unity can be read, and smaller divisions estimated.*

The equation (2) is graphically delineated by the line joining the two points on the co-ordinate axes whose number is equal to "− A," *i.e.*, the coefficient of the second term of the given quadratic with its sign reversed. This line need not actually be drawn, as the straight line *ab* on the gelatine plate can be brought into position over the above-named points, in order to mark the straight line (2). It is always parallel to the diagonal AC.

As before remarked, the graphic representations of the equation (3) are rectangular hyperbolas whose asymptotes coincide with the co-ordinate axes, and whose branches lie in opposite quadrants; thus positive values of B would be found to the right above, and to the left below, and negative values to the left above, and the right below.

These hyperbolas, calculated for every other value from $B = 0$ to $B = 100$, and from $B = 0$ to $B = -100$, have been drawn on the table, and the values of B marked on the margin.

Thus the roots of equation (1) can easily be obtained by finding the points of intersection of the hyperbola for the special value of B (in equation (3)) with the straight line given by the value of − A in equation (2), and reading off the abscissæ and ordinates.

This results in four numbers being obtained, but on examination it will be found that one abscissa is equal to one ordinate, and *vice versâ*, due to the symmetrical position of the hyperbola and the straight line with regard to the line BD of the table.

* In copying this table the sub-divisions have been reduced to fifths, but with a larger table tenths would be used.

Example.—To solve the equation

$$x^2 - 7x + 10 = 0$$

Here we have

$$-A = +\ 7.$$

$$B = +10.$$

Place the straight line *ab* of the gelatine plate over the points marked +7 on the co-ordinate axes of the table, then it will cut the hyperbola marked +10 in two points whose abscissæ give the values $x_1 = +2$ and $x_2 = +5$; these are the required roots of the equation.

The ordinates would give the same results, and, therefore, need not be read off.

II.—Equations of the Third Power.

The general form of the equation of the third power is

$$x^3 + Ax^2 + Bx + C = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (4).$$

Let $x_1 x_2 x_3$ be the roots of this equation, then

$$x_1 + x_2 + x_3 = -A \ldots\ldots\ldots\ldots\ldots\ldots (5).$$

$$x_1 x_2 + x_1 x_3 + x_2 x_3 = \quad B \ldots\ldots\ldots\ldots\ldots\ldots (6).$$

$$x_1 x_2 x_3 = -C \ldots\ldots\ldots\ldots\ldots\ldots (7).$$

Let

$$x_2 + x_3 = z \quad \ldots\ldots\ldots\ldots\ldots\ldots (8),$$

and

$$x_2 x_3 = y \quad \ldots\ldots\ldots\ldots\ldots\ldots (9),$$

then equations (5), (6), and (7) become

$$x_1 + z = -A \quad \ldots\ldots\ldots\ldots\ldots\ldots (10).$$

$$x_1 z + y = \quad B \quad \ldots\ldots\ldots\ldots\ldots\ldots (11).$$

$$x_1 y = -C \ldots\ldots\ldots\ldots\ldots\ldots (12).$$

Eliminate z out of equations (10) and (11), then

$$y = x_1^2 + Ax_1 + B \ldots\ldots\ldots\ldots\ldots\ldots (13).$$

The solution of the two equations (12) and (13) for x_1 and y gives in general three values for x, and three for y, which are the desired roots of the given equation (4), and the attendant values of the products of both the other roots.

How this solution can be effected graphically shall be shown.

Regarding x_1 and y as rectangular co-ordinates on the accompanying table, then equation (12) represents a conjugate hyperbola, and equation (13) a parabola.

For varying values of C, the hyperbolas drawn in the table are obtained as described above.

From equation (13) it will be apparent that the parabola has a parameter constantly equal to unity, its axis is parallel to the ordinate axis of the co-ordinate system, and its open side is always turned upwards.

In order to find the position to be occupied by the vertex, write the equation to the parabola in this form—

$$y-\left(B-\frac{A^2}{4}\right)=\left(x_1+\frac{A}{2}\right)^2 \dots\dots\dots\dots\dots\dots(14),$$

from which it is apparent that the vertex of the parabola has the abscissa

$$=-\frac{A}{2},$$

and the ordinate

$$=B-\frac{A^2}{4}.$$

This parabola is of the shape shown on the accompanying table, and only requires to be placed in position on the point indicated above to enable the observer to read off its intersections with the hyperbola, whose value is C, in order that the roots of the given equation may be obtained.

Example 1.—Let the equation $x^3-4x^2+x+6=0$ be given; then we have

$$A=-4.$$

$$B=+1.$$

$$C=+6.$$

Hence the vertex of the parabola has the co-ordinates

$$-\frac{A}{2}=+2.$$

$$B-\frac{A^2}{4}=-3.$$

The determining hyperbola is shown by

$$-C = -6.$$

Now lay the transparent gelatine plate with the parabola vertex b on the point $x = +2$, $y = -3$, on the table, and bring the axis ab of the parabola parallel to the ordinate axis, the open side of the parabola turned upwards; then the parabola cuts the hyperbola marked "-6" in three points whose abscissæ are

$$\left.\begin{array}{l} x_1 = -1. \\ x_2 = +2. \\ x_3 = +3. \end{array}\right\}$$

These are the roots of the given equation.

Example 2.—Let the given equation be

$$4x^3 - 45x^2 + 92x + 96 = 0.$$

Divide by 4; then

$$x^3 - 11{\cdot}25x^2 + 23x + 24 = 0.$$

Hence

$$A = -11{\cdot}25.$$
$$B = +23.$$
$$C = +24.$$

Then

$$\left.\begin{array}{r} -\dfrac{A}{2} = +\ 5{\cdot}62 \\ B - \dfrac{A^2}{4} = -\ 8{\cdot}64 \end{array}\right\} \text{(vertex of parabola).}$$

$$-C = -24 \qquad \text{(hyperbola).}$$

On applying the parabola to the table, it will be found to cut the (-24) hyperbola in the branch situated in the right lower quadrant in two points, which give the roots $x_1 = +4$ and $x_2 = +8$.

The intersection of the parabola with the branch of the hyperbola lying in the upper left quadrant falls beyond the table; but the third root can be readily obtained from the consideration that

$$-A = x_1 + x_2 + x_3,$$

which in this case would be

$$x_3 = +11{\cdot}25 - 4 - 8 = -0{\cdot}75.$$

Should the value of C not come out an even number, then the necessity arises to interpolate between two of the given hyperbolas of the table. Such interpolation must be done by eye.

Should it happen that all the intersections marking root-values fall outside the table, then by a slight transformation the roots can be reduced to the desired size.

Substitute $$x = m\xi \qquad \text{.............................(22)},$$

or $$x = \xi + m \qquad \text{.............................(23)},$$

in the given equation, solve the resulting equation for ξ, and finally determine the value of x from equation (22) or (23).

To illustrate the substitution in equation (23), take the following:—

Example 3.—Let $x^3 - 38x^2 + 461x - 1{,}768 = 0.$

Also let $$x = \xi + 10;$$

then, to determine the coefficients of the new equation, we get the following:—

$$\begin{array}{r|llll} 10) & 1 & -38 & +461 & -1{,}768 \\ \hline & 1 & -28 & +181 & +42 \\ & 1 & -18 & +1 & \\ & 1 & -8 & & \end{array}$$

Then the equation for ξ becomes

$$\xi^3 - 8\xi^2 + \xi + 42 = 0.$$

Wherein

$$A = -\ 8.$$
$$B = +\ 1.$$
$$C = +42.$$

Hence

$$\left.\begin{array}{r} -\dfrac{A}{2} = +\ 4 \\ B - \dfrac{A^2}{4} = -15 \end{array}\right\} \text{(vertex of parabola).}$$

$$-C = -42 \quad \text{(hyperbola).}$$

Applying the plate in the proper direction to the table (so that the point a is on the point represented by the co-ordinates $+4$ and $+5$), then one root is obtained directly, viz., $\xi_1 = +7$.

For the other two roots, solve the equations

$$\xi_2 + \xi_3 = -A - \xi_1 = +1.$$

$$\xi_2 \xi_3 = -\frac{C}{\xi} = -6.$$

By placing the plate with the line *ab* over the points marked + 1 on the co-ordinate axes, two intersections are obtained with the hyperbola marked − 6, giving the roots

$$\xi_2 = -2 \text{ and } \xi_3 = +3.$$

The desired roots can now be found from the equation $x = \xi + 10$, and are

$$x_1 = +17, \quad x_2 = +8, \quad x_3 = +13.$$

III.—Equations of the Fourth Power.

If $$x^4 + Ax^3 + Bx^2 + Cx + D = 0 \quad\text{.................(24)},$$

is an equation of the fourth power, then the following relations exist between the roots x_1, x_2, x_3, x_4 and the coefficients A, B, C, D :—

$$x_1 + x_2 + x_3 + x_4 = -A \quad\text{......(25).}$$

$$x_1x_2 + x_1x_3 + x_1x_4 + x_2x_3 + x_2x_4 + x_3x_4 = B \quad\text{.........(26).}$$

$$x_1x_2x_3 + x_1x_2x_4 + x_1x_3x_4 + x_2x_3x_4 = -C \quad\text{.........(27).}$$

$$x_1x_2x_3x_4 = D \quad\text{......(28).}$$

Make
$$x_1 + x_2 = m \quad\text{.........................(29),}$$

$$x_3 + x_4 = n \quad\text{.........................(30),}$$

$$x_1x_2 = p \quad\text{.........................(31),}$$

$$x_3x_4 = q \quad\text{.........................(32),}$$

then equations (25), (26), (27) and (28) become

$$m + n = -A \quad\text{......................(33).}$$

$$mn + p + q = B \quad\text{......................(34).}$$

$$mq + np = -C \quad\text{......................(35).}$$

$$pq = D \quad\text{......................(36).}$$

From the two equations (33) and (35) we obtain

$$m=-\frac{Ap-C}{p-q} \text{ and } n=\frac{Aq-C}{p-q}.$$

Substitute these values of m and n in equation (34), and we get

$$-\frac{(Ap-C)(Aq-C)}{(p-q)^2}+p+q=B.$$

Transforming this equation in view of the facts that

$$pq=D \text{ and } (p-q)^2=(p+q)^2-4D,$$

we get

$$(p+q)^3-B(p+q)^2+(AC-4D)(p+q) -[C^2+D(A^2-4B)]=0 \quad \ldots\ldots\ldots(37).$$

Now let $$p+q=z \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(38).$$

Then, to solve the given equation of the fourth power, the following rule holds :—

Obtain a root of the equation

$$z^3-Bz^2+(AC-4D)z-[C^2+D(A^2-4B)]=0 \quad \ldots\ldots(39),$$

by the previously-described method ; then determine from

$$p+q=z \text{ and } pq=D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(40),$$

the value of p and q by the method above described for equations of the second power ; further, from

$$m+n=-A \text{ and } mn=B-z \quad \ldots\ldots\ldots\ldots\ldots(41),$$

obtain the values m and n in the same manner, having regard to the condition in

$$mq+np=-C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(35).$$

Finally, from the equations

$$x_1+x_2=m \text{ and } x_1x_2=p \quad \ldots\ldots\ldots\ldots\ldots\ldots(42),$$

obtain the roots x_1 and x_2, and from

$$x_3+x_4=n \text{ and } x_3x_4=q \quad \ldots\ldots\ldots\ldots\ldots\ldots(43),$$

the roots x_3 and x_4.

If equation (39) has three real roots, it is immaterial which of these three are used for the subsequent working, as the same four values are always obtained for x_1, x_2, x_3, and x_4.

Example.—Let $x^4 - x^3 - 7x^2 + x + 6 = 0$ be the given equation whose roots are required.

Here

$$A = -1.$$
$$B = -7.$$
$$C = +1.$$
$$D = +6.$$

And in this case equation (39) becomes

$$z^3 + 7z^2 - 25z - 175 = 0.$$

Now let $z = 2\xi$; then we have

$$\xi^3 + 3{\cdot}5\xi^2 - 6{\cdot}25\xi - 21{\cdot}87 = 0.$$

In which

$$A' = +\ 3{\cdot}5.$$
$$B' = -\ 6{\cdot}25.$$
$$C' = -21{\cdot}87.$$

Hence

$$\left.\begin{aligned} -\frac{A'}{2} &= -1{\cdot}75 \\ B' - \left(\frac{A'}{2}\right)^2 &= \quad 9{\cdot}31 \end{aligned}\right\} \text{(vertex of parabola).}$$

$$-C' = +21{\cdot}87 \quad \text{(hyperbola).}$$

By the intersections of the parabola and hyperbola, three values are obtained, viz. :—

$$\xi_1 = +2{\cdot}5,$$
$$\xi_2 = -2{\cdot}5,$$
$$\xi_3 = -3{\cdot}5;$$

hence z has the three values

$$z_1 = +5,$$
$$z_2 = -5,$$
$$z_3 = -7.$$

Each of these three values is suitable for the purpose of obtaining the required roots.

(a). Take, for instance, $z = +5$; then, from equation (40),

$$p + q = +5,$$

$$pq = +6,$$

from which, with the aid of the table, $p = 2$ and $q = 3$.

From equation (41) we get

$$m + n = +\ 1,$$

$$nm = -12,$$

from which the values of m and n are found to be $+4$ and -3. Which of these belongs to m and which to n must be decided by equation (35), from which

$$3m + 2n = -1;$$

hence $$m = -3 \text{ and } n = +4.$$

Equations (42) now become

$$\left.\begin{aligned} x_1 + x_2 &= -3, \\ x_1 x_2 &= +2, \end{aligned}\right\}$$

from which $x_1 = -1$ and $x_2 = -2$.

Finally, equations (43),

$$\left.\begin{aligned} x_3 + x_4 &= +4, \\ x_3 x_4 &= +3, \end{aligned}\right\}$$

which give $x_3 = +1$ and $x_4 = +3$.

Hence the required roots are

$$x_1 = -1.$$

$$x_2 = -2.$$

$$x_3 = +1.$$

$$x_4 = +3.$$

(*b*). Supposing the value $z = -7$ had been taken to obtain the value of these roots, then the working would have been

$$\left.\begin{aligned} p+q &= -7 \\ pq &= +6 \end{aligned}\right\} \quad \text{..........................(40).}$$

$$\left.\begin{aligned} p &= -1. \\ q &= -6. \end{aligned}\right\}$$

$$\left.\begin{aligned} m+n &= +1 \\ mn &= 0 \end{aligned}\right\} \quad \text{..........................(41),}$$

from which the values of m and n appear to be 0 and $+1$.

Having regard to

$$-6m - n = -1 \text{..........................(35),}$$

we find

$$\left.\begin{aligned} m &= 0. \\ n &= +1. \end{aligned}\right\}$$

Further,

$$\left.\begin{aligned} x_1 + x_2 &= 0 \\ x_1x_2 &= -1 \end{aligned}\right\} \quad \text{..........................(42),}$$

hence

$$\left.\begin{aligned} x_1 &= +1. \\ x_2 &= -1. \end{aligned}\right\}$$

$$\left.\begin{aligned} x_3 + x_4 &= +1 \\ x_3x_4 &= -6 \end{aligned}\right\} \quad \text{..........................(43).}$$

$$\left.\begin{aligned} x_3 &= +3. \\ x_4 &= -2. \end{aligned}\right\}$$

The same four roots would also have been obtained by using $z = -5$.

PAPER IX.

REPORT ON THE SURVEY OPERATIONS CARRIED OUT BY THE ANGLO-PORTUGUESE COMMISSION IN EAST AFRICA IN 1892.

By Captain S. C. N. Grant, R.E.

THE following account was written primarily as a report for the Foreign Office, but, at the same time, with the view of its possible publication as a R.E. *Professional Paper*. When submitted to the Foreign Office, the Secretary of State for Foreign Affairs sanctioned its publication in the *Corps Papers*. To anyone accustomed to carry on a survey of the nature described, it contains nothing new. It has been written in greater detail than many may consider necessary in the hope that, being founded entirely on practical experience, it may assist any officer undertaking for the first time a survey of a similar nature, and such a survey approaches nearly the work that any Engineer officer might be called upon to perform on active service in an unmapped country.

It is, however, in itself not complete, for, as a rule, no mention has been made of many points which, though interesting and important, have been fully described by Major the Hon. M. G. Talbot, R.E., in his admirable Paper on "Military Surveying" in the *Corps Papers* for 1888.

The line of boundary which had to be determined by the Commissioners and surveyed was that described in Article II. of the Anglo-Portuguese Convention, signed at Lisbon on the 11th June, 1891, as follows :—

"A line which, starting from a point opposite the mouth of the river Aroangwa, or Loangwa, runs directly southwards as far as the 16th parallel of south latitude, follows that parallel to its intersection with the 31st degree of longitude east of Greenwich, thence running eastward direct to the point where the river Mazoe is intersected by the 33rd degree of longitude east of Greenwich ; it follows that degree southwards to its intersection by the 18° 30′ parallel of south latitude ; thence it follows the upper part of the eastern slope of the Manica plateau southwards to the centre of the main channel of the river Sabi, follows that channel to its confluence with the Lundi, whence it strikes direct to the eastern portion of the frontier of the South African Republic.

"It is understood that in tracing the frontier along the slope of the plateau, no territory west of longitude 32° 30′ east of Greenwich shall be comprised in the Portuguese sphere, and no territory east of longitude 33° east of Greenwich shall be comprised in the British sphere. The line shall, however, if necessary, be deflected so as to leave Mutassa in the British sphere, and Massi-Kessi in the Portuguese sphere."

The greater portion of the boundary, namely, that between the rivers Mazoe and Sabi, extending from latitude 16° 30′ S. to 21° 20′ S., depended, therefore, upon absolute longitude from Greenwich.

The route decided upon for entering the country was that from Beira, on the coast, by march up what is called the Pungwe river route, to Massi-Kessi, which place would then naturally become the base of operations of the Commission, and the determination of longitude would conveniently be made somewhere in its locality. It was necessary, therefore, before leaving England, to decide upon the method or methods to be employed for the determination of longitude, so that the necessary instruments could be taken out.

May was the earliest month in which it was desirable to march up the Pungwe without running too great a risk of malarial fever ; and the rains, which generally commenced in October, would render survey work practically impossible when the regular and continuous rain had once set in, probably in November or December. The working season was reduced, therefore, to the period between the beginning of June and the middle of November, that is, five and a-half months, and as no portion of the boundary in the vicinity of Massi-Kessi could be fixed until the longitude had been determined, a great consideration in deciding upon the method to be employed for this determination was, therefore, *time ;* another consideration was the difficulty of carrying on, in the early months of the cold season, a triangulation, owing to the long grass with which the whole country, up till July or August, when it is burnt, is covered. This grass, which varies from five or six feet to eight or ten feet in height, offers such an impediment to any movement off the regular native tracks as to render the work of carrying on a triangulation extremely arduous and slow.

To determine the longitude, four methods were considered; these were:—

1. By moon culminations.

2. By occultations.

3. By either a triangulation or transmission of watches between Massi-Kessi and Fort Victoria, which could be placed in telegraphic communication with the observatory at Cape Town. By the time the Commission arrived at Massi-Kessi, the telegraph from Cape Town had been completed to Fort Salisbury, which place would probably have been more convenient to connect with Massi-Kessi, since all communications from Umtali passed through Fort Salisbury, and the tracks between those two places are more direct than those, if any exist, between Umtali and Fort Victoria. No good direct track existed, I believe, between Umtali and Fort Victoria.

4. By carriage of watches from Beira on the coast. Owing to the flatness of the country, the extreme height of the grass on this coast plain, and the presence of marshes and swamps, a triangulation from Beira was out of the question; moreover, the longitude of Beira itself was not at the time believed to have been very accurately determined.

It was decided to employ one of the absolute methods (1) and (2), and to check the result by one of the methods (3) and (4). Mr. Christie, the Astronomer Royal, very kindly considered the relative advantages and disadvantages, under the particular circumstances, of methods (1) and (2), and recommended that, since the calculations would have to be made and a determination arrived at on the spot, and before the moon's errors on the nights of observation could be obtained from any fixed observatory, the method of moon culminations should be employed.

As it was intended to take out under any circumstances four half-chronometer watches for running meridian distances, it was not necessary to decide which method, (3) or (4), should be employed until the arrival of the Commission in the country, when method (4), namely, that of carrying time from the coast, was carried out by Major Freire d'Andrade, of the Portuguese Commission.

The members of the Commission available for surveying duties were Major J. J. Leverson, R.E., the British Commissioner, who, in addition to his other work, added very much to the mapping by making careful and accurate route sketches of all the tracks followed by him, Captain S. C. N. Grant and Lieutenant C. S. Wilson, and five non-commissioned officers, Royal Engineers.

As it was anticipated that all transport would have to be done by porters, it was necessary to limit the weight of instruments, and, indeed, of all other stores and equipment as much as possible, and to arrange for no case or load exceeding 50lbs. in weight. The following is a list of the instruments and survey stores taken :—

Portable transit and stand.
7-inch transit theodolite.
6-inch transit theodolite.
Box chronometer, regulated to keep sidereal time,
4 half-chronometer watches, mean time.
4 plane tables.
Measuring chain, 100 feet.
Steel tape, 100 feet.
2 heliographs.
2 heliostats.
2 telescopes, with stands.
2 magnesium flash lamps.
2 bull's-eye lanterns.
2 gallons colza oil.
½ pint olive oil for instruments.
2 aneroids.
1 boiling-point apparatus.
7-inch sextant.
Artificial horizon, portable.
6-inch circular protractor, with vernier.
2 sets maximum and minimum thermometers.
2 pocket thermometers.
8 spare spirit-level tubes, for replacing broken level tubes in the instruments.
Stationery and drawing instruments, including plotting scales specially divided to the scale of the survey.

The transit was specially constructed by Messrs. Troughton and Simms ; it had a focal length of about 22 inches, a 2½-inch object glass, and oculars giving magnifying powers of 28, 50, and 60. Stars of the sixth magnitude could be observed. The reticule was fitted with seven threads, the whole of which was moved directly by a micrometer screw. It was supplied with a Bohnenberger eye-piece and mercury collimator. The telescope and striding level were packed in one case, and the Y's, base plate, and accessories in another case. Both these cases were well within the limit of 50lbs., and the whole arrived at Massi-Kessi in perfect order, and gave the greatest satisfaction throughout.

A well-braced tripod pedestal, which had been for some years in store at the Ordnance Survey Office, and which had become thoroughly seasoned, was also taken out and made use of. In the top of the pedestal three gun-metal discs were let in, upon which rested the feet of the levelling screws fitted in the base plate. In the disc, at one end, was drilled a conical hole, in which the conical base of the levelling screw fitted accurately; in each of the two discs for the foot screws, at the other end of the base plate, were cut horizontal grooves of a cross section, also fitting the base of the screws. The object of the grooves was to allow of expansion and contraction in the length of the base plate. This pedestal weighed about 30lbs. The axis of the instrument was levelled by the foot screws only, which were, of course, fitted with clamping nuts, and the only means of adjustment in azimuth was by antagonistic screws moving laterally the V block in one of the uprights. This method of adjusting the V block has one great disadvantage in necessitating the operator taking his eye from the instrument in order to alter the adjustment. This, perhaps, would be a small disadvantage when some days are available for completing the adjustments of the instrument. The error in azimuth could, after a night's observation, be calculated; also, the value of a turn of the antagonistic screws could readily be ascertained, and the error reduced to within working limits.

When the Commission, however, arrived at Massi-Kessi, the moon was culminating at a time when the moon-culminating stars could be observed. It would have been highly inconvenient to have waited until the next lunation, and, therefore, the instrument had to be set up as quickly as possible, and it would have been very convenient to have completed the adjustments during the first night. The transit had been adjusted during the day on a meridian mark fixed from somewhat hurried observations made with a 6-inch transit theodolite, and transits for longitude, as well as for azimuth and level errors, were made the same night. The results of these observations showed an excessive error in azimuth, which had to be taken out the following night. This was finally done by adjusting the centre wire on σ Octantis at culmination, but not till several ineffectual attempts had been made with other stars whose motion was more rapid than that of the star mentioned. For a portable instrument, therefore, which may have to be constantly set up, and with little time to spend on adjustments, I would suggest the advisability of having some means by which the final adjustment in azimuth can be made by the operator without removing his eye from the ocular. I have since suggested to Mr. Simms a continuous screw running in a thread right through the movable V block, but he fears that the screw thread might get worn, and thinks the object might be better gained by some arrangement at the base of the stand.

The mercury collimator was not perfectly successful. It was at first placed on the base plate of the stand, and it was found that whenever the telescope was touched with the hand, no matter how lightly, sufficient vibration was transmitted to the surface of the mercury to make the adjustments difficult. An arrangement was then made by which the collimator was supported on the wooden pedestal and clear of the telescope stand, but the result was the same. The cause would appear to have been, therefore, in the wooden pedestal, but as neither the pedestal nor the transit were brought home (they were transferred to the British South Africa Company), I have been unable to make any further experiments as to the cause.

The vibration could certainly be checked by placing a piece of parallel glass on the surface of the mercury, but this would be objectionable.

It was intended to take out two 6-inch theodolites, but the 7-inch was taken because a second 6-inch was not available, both instruments being lent by the Ordnance Survey Department.

An agreement had previously been drawn up between the British and Portuguese Commissioners, in which it was agreed that the verniers of instruments, used for the more important observations, should read at least to 10 seconds of arc.

The 6-inch transit was packed in two boxes, but the 7-inch in one; the former arrangement was preferable, because whilst the two boxes could be strapped together to make one load for marching, they could be separated and formed into two light loads for ascending very steep and rough mountains. The stands of both instruments were of the braced pattern, and were provided with padded canvas caps for protecting the head whilst being carried; this was a very necessary precaution. I am inclined to think that, for an extended triangulation, the telescopes generally provided with 6-inch instruments are not sufficiently powerful, and often much time was lost in picking up points, and in some instances the lengths of the sides of the triangles were restricted to the powers of our telescopes, when they could, with advantage, have been more extended. An instrument specially constructed for work of this nature should have a much larger objective and greater magnifying power than those usually provided.

Major Talbot recommends, for facilitating getting a star into the field of the telescope, rough fore and back sights aligned parallel to its axis. It is certainly worth having these fitted, although after practice with one particular instrument one gets into a knack of aligning it pretty rapidly without them. If an instrument is not so fitted, after having once picked up a star, set one of the arcs after each reversal of the telescope, the vertical arc to the complement, or the horizontal to the supplement, of the last reading, according as the star's principle motion is in azimuth or in altitude. In observing, it is quicker and more satisfactory to read and allow for the level error than to endeavour to keep the bubble in the centre of the run.

The box chronometer, regulated to sidereal time, was taken for use with the transit only. This was lent by the Admiralty, and was received only on the morning of the day the Commission left Southampton, and was not unpacked until our arrival on the coast, when it was found that a chronometer beating fifths had been sent in mistake for one beating half-seconds. This was awkward, since for eye and ear observing it is desirable, if not absolutely necessary, that the beats should correspond with the divisions on the dial. The difficulty was in someway got over by painting out the seconds dial with Chinese white, and re-dividing it into 75 divisions or seconds. The transits were observed and booked in these seconds, 75 to a minute, and converted into ordinary seconds during the calculations.

The four half-chronometer, or deck watches, were taken for running meridian distances.*

Of the four plane-tables, two were large ones measuring 26 inches by 21 inches outside the frames; they were supported on braced tripods, and levelled by three foot screws. The straight-edge could be fitted, by means of thumb-screws, either with the ordinary sights or with a telescope. Magnetic needles, four inches in length, in

* Take care that, on board ship, the watches are kept at a safe distance from the dynamo.

troughs, could be fitted by similar means on the straight-edge. The legs were made on a telescopic pattern, so that the whole of each table complete fitted into a box 2 feet $5\frac{1}{2}$ inches long, 1 foot 10 inches wide, and $7\frac{1}{2}$ inches deep. The weight of each table complete in box was about 50lbs.

The other two plane-tables were of the ordinary W.D. pattern, and answered their purpose very well, but the small brass projections, which retain the clamping fillets in position, wore out and did not, after a time, fulfil their object; and for sketching on a small scale, when one piece of paper lasts a considerable time, some method of fixing these fillets in position more permanently might well be devised.

For small-scale work the large plane-tables were unnecessarily large, and when a regular triangulation is being carried on with other instruments, the telescopic alidade is superfluous, unless the sides of the triangulation be very long, and the detail required to be fixed with great accuracy. A special map, on a scale of two miles to an inch, was made of about 600 square miles of the country around Massi-Kessi. Only two or three trigonometrical points were available at the time, and the triangulation had to be extended and the detail sketched with a plane-table. In this case the large-sized table and telescopic alidade were eminently useful, and the work done fitted exactly on trigonometrical points, subsequently determined.

The steel tape purchased from Chesterman was only used for laying out a standard for testing the chain with which the base was measured at Massi-Kessi. A table of expansion for temperature was obtained for the tape when it was purchased.

The heliographs and heliostats were most useful, and were constantly in use.

Good telescopes save no end of time when picking up points, and too much trouble cannot be taken to get the best procurable, and like everything else, they should be tested, if possible, before leaving England.

The magnesium flash lamps were intended for signalling distant points by night. They are made for photographic purposes, but by a little manipulation, and by using an increased amount of magnesium powder, they can be made to give a very good flash, and weigh next to nothing. They were not, however, made use of, as the presence of sunshine always permitted distant points being signalled by day with the heliograph.

Colza oil is nasty stuff to pack with other things. On the march a small bottle of oil, bull's-eye lantern, and axis lamp of instrument, were packed in an old preserved meat tin, to which a handle had been extemporized with a piece of wire, and carried by the bearer in his hand, or else hung outside his ordinary load. I think it would be better to have all the lanterns, including the small axis lamps, arranged to burn candles, which would be cleaner, and save all the time necessary for trimming the lamps when oil is used.* With one bull's-eye lantern, and the axis lamp, half-a-gallon of oil was found sufficient for above 30 nights' observing.

The aneroids, chosen to read altitudes well within the limits likely to be met with, were constantly in use, both for recording heights, and pressures at the times of observations. They were tested before leaving home, and again compared with a mercurial barometer on H.M.S. *Racoon* at Beira. Readings by a boiling-point apparatus, a very compact little instrument, purchased from Casella, were obtained on the coast both going and returning, and at frequent intervals whilst in the country, as a check on the aneroids.

The sextant, an 8-inch, was not used, except for observing a few meridian altitudes for latitude on the way from the coast to Massi-Kessi, as the transit theodolites were always used subsequently for astronomical observations. A sextant might often be of use for a detached party, when a theodolite is not required for triangulating, or for observing azimuths, and when the weight to be carried is a consideration; but in these circumstances a 6-inch sextant would probably be sufficiently accurate. Personally, I have never observed with one smaller than 6-inch, and this is certainly the smallest size I should be inclined to use if any accuracy at all be required, although they are made as small as 3-inch. For observing the altitude of stars with a sextant, especially if the observer has not had much practice with the instrument, it should be fitted with a small spirit level on the index arm, as recommended in § 88, Vol. II., *Chauvenet's Astronomy*.

The artificial horizon taken was one of a portable pattern purchased from Casella. It consists of two shallow cylindrical vessels of iron, fixed together base to base. The upper vessel is provided

* Since writing the above, being told that the candle arrangement is not always successful, I have tried one, supplied with a 7-inch transit. The attempt was not successful; the heat from the body of the lamp was conducted through the metal to such an extent as to melt the candle in the tube in which it is held. It might be possible to remedy this.

with a glass top in any iron ring, which screws on and off. For carriage the mercury is kept in the under vessel, and when required for use can be run into the upper vessel by giving the two vessels a slight circular movement, the one on the other, by which a hole in the top of the lower vessel is made to coincide with a hole in the bottom of the top one. The whole thing is very neat and portable, being carried in a small case about five inches diameter and one and a-half deep. In practice it was not found entirely satisfactory; when used without removing the glass cover, the true reflected image of the sun was found confused with a number of other reflected images. This could be obviated by removing the glass top, but then the mercury, being exposed, would be rendered unsteady by the least wind, and would collect no end of dust, more especially if placed on the ground.

Sheets of graticules, on the scale to which the survey was to be plotted, four geographical miles to the inch, and on a recognized projection, were prepared before leaving England.

The Commission arrived at Mapanda's Kraal, about 75 miles by water up the Pungwe river, on 28th April, and after two days' work unpacking instruments and stores, and arranging the loads for the bearers, left Mapanda's on the afternoon of 1st May to march to Massi-Kessi. On this march a rough traverse sketch was made of the track. As no points could be fixed, and, owing to the height of the grass, as they could not have been seen if they had been fixed, the bearings had to be laid down by compass or the sun's azimuth; and since the direction was nearly east and west, it was checked every two or three days by a meridian altitude of the sun for latitude. The distances were set off by time, and although these became somewhat exaggerated, owing to the difficulty of making without experience allowance for the winding of the path, the whole line was subsequently equated and plotted after the determination of the position of Massi-Kessi. At Mandigo's Kraal, five days' march from Mapanda's, the Commission halted to allow the bearers being sent back to bring up more loads from the coast; and as this would take about twelve days, and the existence of several kopjes and a range of hills to the west offered facilities for triangulating, it was decided to measure a base and start a triangulation, with the object of carrying it on, if possible, to Massi-Kessi, or of connecting it up with any triangulation subsequently carried out. This was done, but not very rigidly. The base measured was only about 5,500 feet in length, but it took three days for the four non-commissioned officers available, assisted by four or five natives, to clear the grass, and one day to measure it, the chaining being done twice, once from each end. During the next few days rounds of angles were taken from five points, only one theodolite being available, and observations taken for latitude and azimuth.

The Commission arrived at Massi-Kessi on 30th May, and as the moon was then culminating in the evening, at an hour when the moon-culminating stars could be observed, it was necessary to get the transit in position as rapidly as possible. A meridian line was at once set out from observations made with a theodolite, and a temporary observatory was rapidly erected by the native porters. It was constructed by fixing uprights in the ground, about two feet apart, on the arc of a circle of 12 feet diameter; a number of horizontal pieces and rafters were lashed to the uprights with strips of bark, and the whole thatched with grass. The opening left in the roof, and half-way down each side on the meridian, was two feet wide. Such an observatory, which took only 24 hours to construct, was cool by day and warm by night, and gave much more interior space than could be obtained with a special observatory tent of a sufficiently light weight. A foundation was made for the tripod pedestal of the instrument by sinking three logs of wood their whole length of about two feet into the ground, and ramming the earth well round them. The legs of the pedestal stood on the tops of these logs, and were fixed to them by means of iron angle-pieces taken out for the purpose. The space inside the bracing, connecting the legs of the pedestal, was then filled in with large stones. The observations taken nightly for level and azimuth errors showed for some time a settlement in this arrangement, but not to any great extent. Observations for longitude were commenced on 3rd June, and were continued throughout the semi-lunation until 15th June. Four nights were, however, cloudy, and only nine determinations were obtained. The mean of these determinations gave the longitude of the observatory 32° 51′ 23·793″ E., with a resulting probable error of ± 7·039 seconds of arc.

As a value for the longitude had to be determined on the spot, it was impossible to refer to any fixed observatory for the moon's errors in right ascension. In order to reduce the amount of the error in the reduction of the longitude due to this, the Astronomer Royal, before the Commission left England, caused to be prepared a table of corrections, to be applied to the moon's right ascension, given in the *Nautical Almanac*. This table was deduced empirically from an inspection of observations in recent years. For further remarks on this table, as well as for an account showing the measure of success attained, compiled after observations throughout the period had been made at Greenwich, reference may be made to a paper by Mr. H. H. Turner, M.A., B.Sc., Chief Assistant at Greenwich Observatory, in the *Monthly Notices of the Royal Astronomical Society*, Vol. LIII., No. 1.

On the part of the Portuguese Commission, Captain Freire d'Andrade determined the longitude by two methods. One by means of a box chronometer, which he had carefully rated before leaving the coast. It was carried slung at the end of a bamboo pole, and rated again, I presume, at Massi-Kessi, but of this I am not certain. The other method was by moon culminations observed with a 6-inch transit theodolite, of power sufficient to observe first and second magnitude stars only. I do not know what proportional value he gave to the determinations by these two methods, but his result placed Massi-Kessi about eight seconds of time more to the east than its position determined by us. Captain Andrade recognized, however, the superiority of our instrument, and satisfying himself as to the care exercised by us in our observations, expressed himself willing to accept our determination.

Whilst Captain Grant was occupied with these observations for longitude, Lieutenant Wilson was engaged, in conjunction with members of the Portuguese Commission, in measuring a base line, and starting a triangulation in the immediate neighbourhood of Massi-Kessi. It had been apparent from the first that the delimitation of the boundary around Massi-Kessi would probably give rise to many difficulties, and Major Leverson decided to have a map, on a scale of two geographical miles to an inch, made of the area extending from the watershed between the Revue and Pungwe rivers and the Odzi river on the west to longitude 33° on the east, and from Mount Vumba on the south to parallel 18° 30′ S. on the north.

The base line was laid out and cleared on the flat ground bordering the Revue river. It was measured with steel chains by both Commissions, and its length, reduced to sea level, was 2 miles 744·7 feet.

The country immediately surrounding Massi-Kessi is fairly mountainous, the peaks rising to an elevation of 2,000 or 3,000 feet above the valley. Most of these are well marked and have distinctive features, rendering them suitable points on which to erect observing stations. On some of them trees had to be cleared away to a considerable extent. Stations were erected on six of the most prominent peaks, and rounds of angles taken from each of these stations; the position of the transit instrument in the temporary observatory was also included as a point in this triangulation.

Massi-Kessi is about 40 miles in a straight line from Mandigo's Kraal, but as a point common to both triangulations was fixed, it was possible to plot both triangulations relatively to one another.

The special survey on a scale of two miles to an inch of the ground around Massi-Kessi was then commenced by Sergeant Clarke, who used one of the large plane-tables, extending the triangulation from the points fixed by Lieutenant Wilson by means of the telescopic alidade. The total area of this survey was about 600 square miles, and it took Sergeant Clarke $3\frac{1}{2}$ months to complete, including the fair drawing, but he was somewhat delayed by the necessity of constantly returning to Massi-Kessi to look after the depôt at that place. Subsequently, on the return of the main body of the Commission from the south, the position of a point in the extreme north-east of this survey was fixed by latitude and azimuth from one of the points at Massi-Kessi, and this agreed exactly with its position on the plane-table sketch.

From the date of arrival at Massi-Kessi, Major Leverson had been making himself acquainted with the general features of the country, and on 7th June proceeded to Umtali, making a rough reconnaissance sketch of the route, and on 15th June he left Massi-Kessi on a reconnaissance to the south, returning on 25th June with a sketch of the route, and of his proposed line of frontier as far as Chimanimani. A survey party, consisting of Captain Grant, Lieutenant Wilson, two N.C.O.'s, Royal Engineers, and 50 native carriers, was then formed to carry on a triangulation and survey of the country along the line of the proposed frontier, extending the work to the flanks sufficiently to include the disputed territory to the west. I may here say that during the whole work, as far as the Sabi river, the same system obtained, Major Leverson in advance, arranging the food supply and the positions of depôts from which the surveying party could draw supplies, both for the Europeans and natives; reconnoitring the country, and furnishing the survey party with sketches of the route and of the line of country to be surveyed. It was decided that south of Massi-Kessi, where the line of frontier was dependent upon the slope of the Manica plateau, between the limits of 32° 30′ and 33° east longitude, a triangulation should be carried on. The main object of this triangulation would be, first, to keep position carefully fixed as regards longitude; errors in latitude would not affect boundary, and could always be checked by observations; and, second, to give sufficient points for filling in the detail so correctly as to ensure the main points of the boundary, when shown on the map, being easily recognized on the ground. Whilst keeping these objects in view, it was necessary to get over the ground as rapidly as possible.

The triangulation was started from the points already determined at Massi-Kessi, and the system of carrying it on was as follows:—Assuming the fates propitious, and the camp pitched about level with and midway between two points to which observations had been made from back stations, and these points, each two or three miles from the track, making a base from which to observe forward of from four to six miles, Lieutenant Wilson and I would first proceed to some point near camp from which the country ahead could be seen, and decide upon the most suitable points to be observed to. If the peaks of the hills or kopjes were not sufficiently acute, some particular trees, rocks, or features of that nature would be selected for observing. We would then go off each to one of the two points to be observed from, taking, besides theodolite and telescope, a plane-table and heliograph, and axes and rope for clearing trees. Upon reaching the point, if it were found a suitable one from which to observe forward it was retained, and if not, the most suitable position near the point was selected. This second point was not used as a satellite station, but the bearing and length of the line joining the two points were noted, and the forward readings from the back stations were corrected to what they would have been had this selected point been observed. The heliograph was then set up on the other station at which observations were being made. The trees being cleared where necessary, the rounds of angles were taken to all prominent objects in view, including, of course, those previously agreed upon. The detail near the station would then be sketched in on the plane-table, and before leaving the station a beacon, suitable for observing back to, would be erected. The beacon erected depended upon the material at hand, but it should always be remembered that a beacon can seldom be too large, for what appears to be a large beacon, and one you think you could not help seeing from anywhere when you are near to it, becomes a very insignificant object five or six miles off. If the ground be fairly clear of trees, and likely to be seen against the sky from the advanced stations, the choice of beacons is simple, for nothing is better than a cairn, or a tree with a bushy top, if to be found near at hand, can be cut down bodily and erected over the point; but in both cases a pole with a white flag, certainly not less than a yard square, and larger if possible, should be added. It is wonderful how the appearance of things changes, and other unsuspected objects appear when one gets away at a distance, and a white flag fluttering in the sun, when once picked up in the telescope, is unmistakable, and at once settles any doubt as to the particular cairn or tree. If the beacons were not likely to be on the skyline, they were generally arranged so that a strip of white calico, about two yards in length, could be stretched so as to be seen from the forward stations. On the arrival of both officers in camp, the triangles, of which all three angles had been observed, were calculated and the points plotted on a diagram. The observations were plotted on the diagram with a 6-inch circular protractor, and the intersections of the lines to points observed from both stations were then transferred to the plane-tables for use in fixing detail when possible during the forward march. Latitudes and azimuths were determined from time to time astronomically as checks on the triangulation. The triangles were calculated out by plane trigonometry, and the points plotted by co-ordinates. At about 80 miles from Massi-Kessi the distance between two trigonometrical points was measured by subtense with the theodolites used as described on p. 55 of Major Talbot's paper on "Surveying" in the *R.E. Corps Papers*, 1888. The distance so obtained was 3481·74 mètres, being 1·8 mètres longer than the distance obtained from the triangulation; the mean of the two values was taken for continuing the triangulation, which was carried on as far as the intersection of the proposed line of frontier with the meridian 32° 30′ E., in latitude 20° 42′ 16″ S., a distance of 160 miles from Massi-Kessi. Forty-four stations were observed from, and the average length of the sides of the triangles was 7·15 miles. The approximate area of the country sketched in detail was 2,000 square miles. The party left Massi-Kessi on 1st July, and arrived at the camp known as Game Tree Camp, near longitude 32° 30′, on 25th August. The daily advance, therefore, on this section of the work, including all delays, was about three miles, and area sketched 40 square miles a day. These rates of progress may appear small to officers accustomed to survey in more open countries, but it is as much as can be done under the unfavourable conditions of East African country at that season of the year. When returning over the same country in October, when the grass had been burnt, and when the atmosphere was free from the smoke caused by miles of grass fires, and cleared by the thunderstorms which commenced in that month, the conditions had materially changed for the better, and a greatly increased rate of progress could be expected were it not for another delaying condition, namely, the constant envelopment of the tops of the hills by clouds.

Although two non-commissioned officers left Massi-Kessi with the surveying party, at no time were the services of both available. One, immediately after starting, developed a sprained knee, and when he was well, the other scalded his foot, and being unable to march, was left behind at Chimanimani. The sergeant had been left behind to do the special map before referred to around Massi-Kessi, and the other two N.C.O.'s, one of whom had an abscess on his foot, were employed in general duties at the depôts.

The hilly country forming the edge of the Manica plateau now receded to the west, and the survey was continued southwards along the meridian 32° 30′ E. to the river Sabi, and in this direction the country changed to a more or less flat plain covered with trees. To have carried on a triangulation over this country without building observing stations, which both time and expense forbade, would have been impossible. Besides, since alternative lines for the boundary could not be proposed, the survey of much detail on the flanks was not required. It was, therefore, decided to fix points by the method of latitudes and azimuths. In carrying out this, the following method which was adopted answered well:— Three parties, which we will call Nos. 1, 2, and 3, were formed, Nos. 1 and 2 being officers, and No. 3 a N.C.O. No. 1 was a day's march in advance of No. 2, and No. 2 the same relatively to No. 3. No. 1 decided on forward points from each of which he could see the back station and also the country in front. On finding a suitable position, a heliograph was lined on the back station, which, when seen, was answered by the heliograph by No. 2. Nos. 2 and 3 signalled their positions to one another in the same way. As there were only two heliographs, No. 3 had a heliostat only. No. 1 observed at noon for latitude and No. 2 observed the azimuth by observing the back and forward stations. No. 1, making a rapid calculation from his highest observed altitude, signalled back the approximate latitude to No. 2, who was thus enabled to plot the approximate position of the advanced point on his plane-table, and thus to regulate his march, and to base any sketching he might be able to do, on the observed points. When No. 2 had finished his observations for azimuth he signalled to Nos. 1 and 3. No. 1, before leaving, marked the station, and left a note in a cleft stick on the track with explanations as to the direction to the station; this note was left by No. 2 for the information of No. 3. Forty-five miles along the meridian to the river Sabi were surveyed in this way in five days, five stations being fixed.

The point fixed near the Sabi, the intersection of the meridian 32° 30′ with the river, and the point of junction of the Sabi and Lundi rivers, were connected by a subtense traverse along the river bed.

The country in advance between the rivers Sabi and Limpopo was almost unknown, and very little information could be obtained about it from the natives. Water was known to be very scarce and tracks very few. It was, therefore, uncertain whether any track would take us near the straight line which would form the boundary. The absence of any food for the bearers rendered it necessary to make this march rapidly and with as small a party as possible. It was decided to make route sketches of the tracks followed, and nightly observations for latitude and longitude. The party consisted of Major Leverson, myself, an interpreter, and 68 bearers. Major Leverson made the route sketches, and I the astronomical observations. The remainder of the Commission, consisting of Captain Lawrence, Rifle Brigade, and Lieutenant Wilson, returned to Massi-Kessi, picking up Surgeon-Captain Rayner at Game Tree Camp. During this return march, Lieutenant Wilson put up the boundary beacons on those portions of the line which had been agreed upon between the British Commissioner and Major Freire d'Andrade, who, for the portion of the line south of Chimanimani, was representing the Portuguese Commissioner; he also extended at one or two places the detail survey.

For determining the longitudes between the rivers Sabi and Limpopo, the time was carried by means of four half-chronometer watches, of which the errors were calculated on leaving the Sabi, and again on our return to the same camp, 18 days subsequently; their rate during the interval was assumed to have been uniform. The four watches fitted in a wooden case specially made for them. On this trip the case used to be wrapped up in a thick woollen jersey and packed, surrounded with clothes, inside a tin case. The bearer who carried the case was warned to be specially careful, and the daily comparisons, although sometimes unsatisfactory, were not more so than when the ordinarily recommended methods were endeavoured to be carried out, and the watches carried on the body, hung vertically at night and nursed generally to quite an inconvenient extent. I cannot remember ever having seen any statement of daily comparisons of watches carried under similar conditions, so that I am unable to form any opinion as to whether the rates of the watches carried should be expected to have been more uniform or not. A table at the end of this report gives the daily differences of the four watches on this trip. Two of the watches had been lent by the Admiralty, and the other two were new watches purchased from Dent.

The distance between the two points, namely, the junction of the rivers Sabi and Lundi and the rivers Limpopo and Pafuri, shown on then existing maps as about 65 miles, was found to be more than 100 miles, and the distance marched by the column going and returning was 315 miles.

The observations taken nightly were generally two stars, N. and S., for latitude, and four stars, two E. and two W., for time. The country was found to be a flat plain covered with bushes and stunted trees, confining the view to one or two hundred yards. Absolutely no hills or other features were visible to assist the sketching done by Major Leverson. These sketches are examples of what can be done with rapid surveying under adverse circumstances. The rate of marching averaged 18½ miles a day. The plane-table was oriented by the compass or by the sun's azimuth. The direction of the track, which wriggled about in a truly African fashion, and which never could be seen more than two hundred yards either way, could only be plotted approximately. The distances marched were estimated by time, and here again great judgment was required in making a proper allowance for the incessant bendings and windings of the track, and yet, when these sketches were compared with the plots of the points fixed by observations, they were found to agree almost absolutely in direction, but to be uniformly short in distance by about 4 or 5 per cent., due, no doubt, to a slightly too great allowance being deducted on account of the windings of the track. This could have been corrected had Major Leverson known in time, but the longitudes obtained astronomically could not be calculated until a rate for the watches had been obtained on our return to the Sabi.

The point on the Limpopo river forming the southern point of the line to be laid out had been determined in 1890 by the Portuguese section of the joint Portuguese and Transvaal Commissions in laying out the boundary between the province of

Lorenço Marques and the Transvaal. Chronometers were carried from Delagoa Bay, and the longitude determined was 31° 22′ 25″ E., whereas our determination was 31° 21′ 52·41″ E., the difference, 32·59 seconds of arc, being equivalent to only 900 yards.

On 28th September the party reached the Sabi on the return journey, and after remaining 24 hours to rest the porters and take observations for rating the watches, continued the return to Massi-Kessi, where Major Leverson arrived on the 15th October. Captain Grant and Lieutenant Wilson, both of whom had been delayed by the sickness of members of their respective parties, did not arrive till later, the former on the 19th October and the latter on the 22nd October.

The rains had to some extent commenced. In September we had had rain on the Limpopo river, and during the early part of October we experienced three days' continuous rain on the Lusita river, and the weather had become unsettled, with heavy thunderstorms at night. But still more work remained to be done. Sergeant Clarke's map was not completed to latitude 18° 30′ on the north, nor to the watershed on the north-west, and Major Leverson was desirous of fixing the meridian 33° E., as far north as the watershed between the rivers Pungwe and Zambesi. Consequently, on the 24th October, the whole Commission, except three of the non-commissioned officers who had to remain at Massi-Kessi sick, started north to Ziramira, a hill near the intersection of parallel 18° 30′ S., and meridian 33° E., which was fixed by azimuth and latitude from Mount Venga, near Massi-Kessi.

The party then separated, Captain Grant and Sergeant Clarke going to the west to complete the map before mentioned, and Major Leverson, with the remainder of the Commission, going north along the meridian. Four points were fixed by observed latitudes and azimuths by Lieutenant Wilson, through country with well-marked hills, but covered with trees, carrying the survey to latitude 17° 57′ S.

During this time thunderstorms were frequent, and the tops of the mountains were for the greater part of the time covered with clouds; and this party on its return march was detained 24 hours on the Pungwe, awaiting the river, which had considerably swollen, to go down.

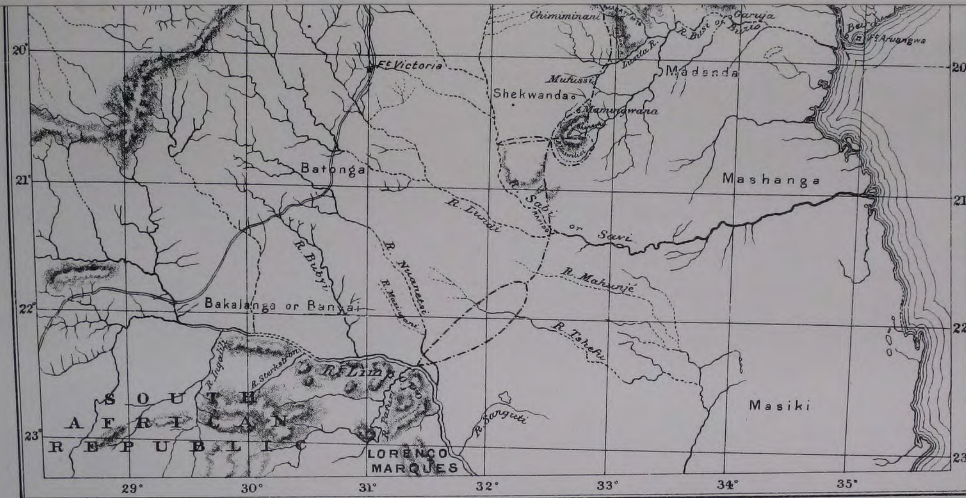
The whole Commission re-assembled at Massi-Kessi on the 12th November, and commenced its march down the Pungwe two days later.

Table of Daily Differences of Four Watches Carried from River Sabi to River Limpopo and Return between September 8th and 28th, 1892.

DIFFERENCES BETWEEN WATCHES.

1 and 2.		1 and 3.		1 and 4.		2 and 3.		2 and 4.		3 and 4.	
Min.	Secs.	Min.	Secs.	Min.	Secs.	Min.	Secs.	Min.	Secs.	Min.	Secs.
+ 0	29	+ 0	13	+ 0	34·5	– 0	16	+ 0	5·5	+ 0	21·5
	17		9		23		8		6		14
	9		0·5		9·5		8·5		0·5		9·5
	0	– 0	14·5	- 0	17		14·5	– 0	17	– 0	2·5
– 0	12		25		33		13		21		8
	23·5		36		52·5		12·5		29		16·5
	35·5		47·5	1	12		12		36·5		24·5
	49		57		27		8		38		30
	59·5	1	7·5		45		8·5		45·5		37·5
1	9·5		18 5	2	2		9		52·5		43·5
	20		26·5		18		6·5		58		51·5
	31		34·5		30·5		3·5		59·5		56
	46		38		41	+ 0	8		55	1	3
	53		54·5	3	11	– 0	1·5	1	18		16·5
2	2	2	1		24	+ 0	1		22		23
	8		11·5		54	– 0	3·5		46		42·5
	9·5		25	4	24		15·5	2	14·5		59
	21		29		40·5		8		19·5	2	11·5
	31·5		36·5		55		5		23·5		18·5
	34·5		53	5	23·5		18·5		49		30·5
	44·5	3	2		38·5		17·5		54		36·5

SION IN EAST AFRICA.



PAPER X.

IRRIGATION IN EGYPT.

BY COLONEL SIR COLIN SCOTT-MONCRIEFF, K.C.M.G., C.S.I., LL.D. (LATE ROYAL ENGINEERS).

LECTURE I.

MAJOR-GENERAL DAWSON-SCOTT has done me the honour to ask me to deliver in this Institute three lectures on the subject of "Irrigation Work in Egypt." In complying with his request, I shall try to remember that the bulk of my audience are Engineers, therefore I must not refrain from handling the subject as an Engineer; and yet the audience are not all Engineers, and irrigation is such a special branch that few who are present can have had, or are likely ever to have, much practical experience of it. I must not, then, be too technical. If I fail to interest you, as I fear I may, be sure that the fault lies in me, not in my subject.

Water, living, life-giving water, can never be a dry subject. But we all know that with the best text to preach on, the preachers may be as dry as dust.

Before entering specially on the irrigation of Egypt, I propose to tell you something of irrigation in general, of the many forms, and of the various countries, in which it is practised. This will occupy us for most of this evening. In my two following lectures I shall confine myself to Egypt.

Irrigation may be defined as the artificial application of water to land, for the purpose of agriculture. It is, then, precisely the opposite of drainage, which is the artificial removal of water from lands which have become saturated to the detriment of agriculture. Irrigation is the process of supplying water to dry land. Drainage is the process of removing water from wet land. A drain, like a river, goes on increasing as affluents join it. An irrigation canal goes on diminishing as water is drawn off it. Later on I shall show how good irrigation should always be accompanied by drainage.

Large rivers in their courses usually pass through three distinct phases. They take their rise in mountains, and come down as torrents with a very rapid slope and a high velocity, scouring out their channel even when, as is usually the case, it is composed of rocks and boulders. Then comes a phase of equilibrium, when the slope and consequent velocity is just sufficient to keep in suspense the alluvial matters that come down, for it must be remembered that any change of velocity affects this alluvium. Raise the velocity, and scouring begins, and alluvium is carried on, that is, the water becomes muddier. Reduce the velocity, and deposit begins to take place, that is, the water becomes clearer. The last phase is when the current can no longer carry forward the alluvium. Then follows steady deposit. This is the deltaic portion of the river. As deposit forms, the bed is raised, very slowly but surely. Then floods come down and over-top the banks, and deposit mud on them. The river bed keeps rising till the ordinary water surface is higher than the general level of the valley, but close to the river itself, the banks raised by deposit are still above it. Then a very big flood comes, and bursts through one of the banks, and a new channel for the river is formed. Perhaps it deserts its old channel altogether. More commonly they both go on running. The process is repeated. The new channel silts up its bed, bursts its bank, and creates yet another channel. In this manner deltas are made. Their slope is away from the rivers instead of towards them. If left uncontrolled, a net work of channels and innumerable islands are formed. The centres of the islands become fever-stricken marshes. Only around the river is there dry land. In the delta of the Irrawaddi I have seen islands of this description. For 200 yards from the water's edge there was dry cultivated soil. In 200 yards more I was in swamp, and dense rushes meeting over my head when riding an elephant. Deltas must be controlled by making artificial banks to the river, banks which the highest flood will not top. The flood waters, confined and hemmed in, rise higher, and acquire greater velocity. This velocity scours out the raised bed, and again the water surface falls. I am to lecture to you on irrigation, and not on river training (although the one is closely connected with the other), so I will not pursue this subject further at present, interesting as it is. Probably the best instance of a great river well controlled by embankments is the Mississippi. A few years ago, an embankment of the great Yellow River in China failed, and some of you may remember the frightful catastrophe that ensued. A whole province was devastated, and thousands, if not millions, of lives were lost.

Irrigation is practised from rivers in all three phases. The peasantry of the Himalayas make the most ingenious little canals from their torrents, and having carefully terraced the steep mountain sides into a series of steps, they grow excellent rice crops, and the same may be seen in the little canals of Granada in Spain, and on the slopes of the Pyrenees. The irrigation of the plains of Northern India depends on rivers more or less in the equilibrium stage. In Southern India and Lower Egypt are excellent instances of delta irrigation.

The simplest form of irrigation is when the water is raised from a river, or lake, or from a well situated in a field. Many thousands of acres are thus watered every year in India. The sculptures and paintings of ancient Egypt show how from the earliest times water was thus raised from the Nile to irrigate the adjoining fields. The means of raising it are generally simple enough ; there is much wasted labour, but the system has the great advantage that there is probably no government interference in the matter. The agriculturist may water his fields as often, or as seldom, as he pleases. There is no permission required from government officials, and if the peasant can ever get water for his lands at all without bribing some one, it is when he obtains it direct from a well or a river.

The simplest and earliest form of water-raising machinery is the pole with bucket and counterpoise, called in India the *Denkli* or *Paecottah*, in Egypt the *Shadoof*. All along the Nile banks from morning to night may be seen brown-skinned peasants, working these *Shadoofs* tier above tier, so as to raise the water 15 or 16 feet on to their lands. It was this that called forth the remark of the unscientific American that all that he could see in the Nile was a long ditch full of water, and men trying to bale it out. With a *Shadoof* it is only possible to keep about four acres watered, so you may imagine what an army is required to irrigate a large surface.

Another method largely used is the shallow bucket worked by strings between two men. This is a very common system in

Northern India, where, in the irrigated districts, throughout the long hot nights, one hears the constant swish swish of the water being thrown on to the field.

A step higher than these is the rude water wheel with earthen pots in an endless chain round it, worked by one or a pair of bullocks. This is used everywhere in Egypt, where it is known as the *Sakya*. I have seen it in Spain. It is a familiar sight in the Punjab and Northern India, where it is called the Persian wheel. I believe it is used in Persia and China. A *Sakya* can keep irrigated from 5 to 12 acres throughout the summer in Egypt, the lift varying from six to one yard, and one pair of oxen being constantly employed.

A very familiar means of raising water in India from wells in places where the spring level is as much sometimes as 100 feet deep is the *Churrus*, or large leather bag, suspended to a rope passing over a pulley and raised by a pair of bullocks which run down a slope as long as the depth of the well.

All these are the primitive water-raising contrivances of the East. Egypt of late years has been more in touch with western civilization, and since its cotton and sugar cane crops yield from £6 to £8 or even £10 per annum, the well-to-do farmer can easily afford a centrifugal pump worked by a fixed or portable steam engine to water his crops. There are now about 380 fixed, and 2,200 portable steam pumps working on the edges of the river and the canals of Lower Egypt.

In lands where there is abundant rainfall, and where it falls at the right season of the year for the crop which it is intended to raise, there is evidently no need of irrigation. But it often happens that the soil and climate are adapted for the cultivation of a valuable crop, but the rain does not fall just when it is wanted, and there we must take to artificial measures. In large tracts of Northern India there is usually from 25 inches to 35 inches of rain in the year, which even in that hot climate would be enough to raise almost any crop save rice, were it equally distributed throughout the year. But in reality about two inches fall in January, and the rest in July, August, and the early part of September. This is enough to raise maize, millet, vetch, even cotton of an inferior kind. But indigo requires constant watering in May and June, for rice wants more than even the rainy season yields; wheat must be sown in moist land in October and November, and be helped on with water in January or February; sugar cane from the time it is planted in March to the time it is cut during the next February must be watered every two or three weeks. For all these irrigation is absolutely necessary.

There are other lands where the rainfall is so very little as to be practically valueless for cultivation, and where there are only two alternatives, irrigation or bareness. Such lands are the valley of the Indus in India, the whole of Egypt, the great plains of Turkomania, north of Persia and east of the Caspian, the plains of Northern Mexico, Colorado, Arizona, Kansas, and parts of California in North America, the western coast of South America, and a great portion of the Continent of Australia. Nor are these rainless countries to be pitied or despised. The rainfall in Cairo is 1·4 inches per annum, yet agricultural land within 20 miles of it sells as high as £80 per acre.

I had a striking instance lately of how completely a country may depend on its irrigation. At the request of the Russian Government I went two years ago to give advice about the irrigation of their last annexed province, Merv, in Central Asia. I found a rainless plain, traversed by a small insignificant river, the Murgháb, which rises in Afghanistan and loses itself in the desert. The population consisted of a sprinkling of half-nomad Turkomans, who drew a scanty water supply from the river. The country was covered with low scrub jungle, but one could see that it only wanted water to be fertile, and also that it had once supported a large population, for everywhere it was intersected by the remains of old canals, some of them still in tolerable condition, but none had contained water for many years. The ancient city of Merv was about 20 miles from the Murgháb. Now it is a mass of lifeless ruins covering an area of 11 miles by 7.

Formerly it was the capital of the Persian province of Khorassan, and it owed its wealth to a very old dam across the Murgháb known as the Sultan Bend, 60 miles south of Merv, which raised the water surface about 18 feet In the year 1783, the Persians in Merv were besieged by their neighbours the Bokhariots from across the Oxus. The besiegers managed to destroy the Sultan Bend. The water surface immediately fell to its natural level. The rich province became a desert, the city a ruin, and so it has remained ever since. It is now to be seen whether or not the Russians will bring back its fallen glories.

Fields irrigated from wells, lakes, or from rivers unaffected by floods, draw water and water alone. But rivers in flood carry along much more than water. Some carry alluvial matter. Some carry fine sand; generally the deposit is a mixture of the two. The Durance in Southern France carries more sand than any river I have seen, and it is a source of unmitigated evil, silting up the canals, and conveying to the fields a minimum of fertilizing matter. I have never known any river that approached the Nile in the richness of its alluvial deposit, and the result is that the plains of Upper Egypt have gone on through all ages, independent of all foreign manures, and never losing their fertility.

Where there is no question of fertilizing mud, and only water is to be had, the most favourable condition of irrigation is when the source of supply is a lake, or more commonly a river issuing from a lake. That splendid Lombard canal, the Naviglio Grande, is of this description. It is drawn from the river Ticino, about 15 miles from the point where it flows out of the Lago Maggiore. Be the rainfall never so heavy, the great lake does not rise much more than seven feet. Be the drought never so prolonged, the surface of the lake does not sink much more than five feet. The stately Ticino, with its beautiful clear water, never varies more than a few feet from highest flood to lowest level, and, in consequence, the Naviglio Grande requires few costly sluices and head works to regulate the supply entering it.

Where there is no moderating lake, a river fed from glaciers will not greatly diminish in volume during the hot months. The greater the heat, the more rapidly the ice melts and the more water is available in the rivers. This great advantage is possessed by the canals drawn from the rivers of the Punjab and other parts of Northern India. I have often observed at Hurdwar, the beautiful gorge where the Ganges leaves the mountains, how during summer there was a regular tide, caused by the melting of the ice during the day, and its freezing again during the night, the river rising and falling in consequence. But this source of supply in the dry season cannot of course affect the immense floods caused by the heavy monsoon rains, and the engineers of Northern India have to do battle with a formidable foe when 12 inches of rain fall in as many hours, which I have known to happen more than once.

Irrigation on a large scale may be divided into three very distinct branches: 1st, that which is only done when the river is in flood; 2nd, that which is done both during flood, and during what the French call the *étiage*, when the river is at its lowest; and 3rd, irrigation affected by lakes, reservoirs, or what in Southern India are termed tanks.

Of the first description is the delta irrigation of Madras, inseparably connected with the genius, energy and industry of General Sir Arthur Cotton, who still lives the father of our Corps, and interests himself in every irrigation question, although he has entered his 90th year, and his first commission in the Madras Engineers dates from the 16th June, 1820.

The three great deltas of Madras are formed by the Godavery, Kistna and Cauvery, rivers supplied neither by lakes nor glaciers, and, therefore, falling to a very low ebb during April and May, but rising surely and rapidly with the monsoon in June. Across these rivers, at the apex of the deltas, are built weirs, locally known as *anicuts*, gigantic works, that of the Godavery being 2½ miles long, and holding up the water 12 feet. With the simplest of appliances, with almost no skilled labour, with funds grudgingly accorded, with hardly any steam power, Sir Arthur Cotton and the school of engineers he created built these great weirs, whose uncouth names, Dowlaishwaram and Bezwada, are hardly known out of India. They do not rest upon rock foundations, but simply on alluvial deposit. The monsoon canals take their rise above them. By a system of sluices the floods are diverted right or left according to the will of the engineer and the requirements of agriculture, and the result is whole provinces of green rice. It is not raised by irrigation alone, for there is a rainfall probably of 30 inches before the crop is ripe; and outside of the deltas, if the monsoon is normal, the whole country is covered with splendid crops of millet and maize raised without any irrigation. But this rainfall is not sufficient to raise rice, and while on the range of western hills, called the Ghats, where these rivers take their rise, rain is never known to fail, its failure in the plains is unfortunately no uncommon occurrence, and may be expected about once in fifteen years. Then the whole country outside the deltas remains barren, while inside all is green—"watered as the garden of the Lord." This was most strikingly shown during the terrible famine of 1776–78. While misery and death swept over the higher lands, the delta rice crops were nearly as good as usual, while the high prices enriched the peasantry beyond all previous experience.

The delta engineer of Madras has not much to do with the distribution of the water. But he has closely to watch the weirs, to control the eddies, fill in deep holes scouring under foundations, see that too much water is not allowed to enter any particular branch, too much pressure not brought to bear on any shaky lock gate; and all this gives him plenty to do. The monsoon over, the canals become dry, and then is the time to attend to foundations, to build new works, and generally to prepare for next monsoon. Colonel Dorward, who has had practical experience, can tell you something of the life of the delta engineer. Where the irrigation goes on all the year round, whether the river is high or low, the duties of the irrigation engineer are naturally more constant. During the floods he has the same duties as I have already described in guiding and controlling the great volumes of water in the river. When the river is low he has to attend to the distribution of the precious element, and see that it is not wasted, for it is certain that he will not have water enough for all who demand it. He must use it, therefore, with economy. He must account for every cubic foot of discharge as he accounts for the public money at his disposal. This means the erection of numerous water gauges, the reports of which are sent to him daily. He must frequently measure the discharge of water in each canal corresponding to a certain height on his gauge, and construct tables to tell him exactly how many cubic feet per sec. of water there are for every inch on his gauges. This measurement of discharges is a never-ending operation. The volume of a stream consists, as you are aware, of the product of its cross section and the mean velocity of its current. The cross section will vary from time to time. Silt deposits will diminish it if the velocity is deficient. Scouring will increase it if the velocity is excessive. Then the velocity depends on the surface slope, and that is not constant, but varies as the canal rises or falls, and it is affected, of course, by any obstruction such as a weir for miles upstream of it.

But the engineer must not only know how much water he is using. He must personally see to its distribution. This is effected by a network of secondary channels, with bed widths of, perhaps, from 15 to 5 feet. The State cannot actually deliver the water on to every man's field. This would involve an army of employés, and would surely lead to every form of bribery, for you will easily understand that the watering of a field exactly at the right time may greatly increase the value of the crop, and it is worth bribing for.

In each case has to be considered up to what point the State should take charge of the water, and where the landowners' property in it and responsibility should begin. In Egypt, the rule is that all watercourses which supply the lands of more than two villages are to be maintained by the State, all smaller ones by the villages concerned.

In Northern India water is supplied through pipes of six inches or nine inches diameter, set in masonry on the banks of the distributary channels. These pipes are the property of individuals or communities, whose lands are watered by them. In Southern France and Italy, instead of the simple pipe are neatly adjusted sluices and shutters.

But where there is a dearth of water these outlets, whether pipes or sluices, must not be opened at the pleasure of the cultivator. Otherwise those near the head of a canal would get far more than their share, and the canal would be dry long before reaching the tail. Perhaps the most convenient system is where it is possible to have a series of Government distributary channels, none longer than eight or ten miles. Then they can be opened or closed in rotation at their heads every alternate week, or in some such way; or the Government employé need only occupy himself with these few head sluices, and not with the many minor ones belonging to each peasant or village. But the configuration of the country may render this impossible. The distributary channel may be twenty or thirty miles long. Then it is necessary to divide it into sections of say eight miles each. The first section is allowed to have open sluices one week, the second section the next week, and if there are only three sections the third, or tail one, may take water whenever it can.

While water is in very high demand, the engineer has little time to think of anything else but its distribution. But fortunately this pressure does not generally last long. Most crops after once being sown can get on for some time without further irrigation. Sometimes there are heavy showers of rain, and for a time the irrigation canals are at a discount. And during these periods the engineer has to design his new works, and see to their execution. He must attend to ordinary repairs. He is sure to require to have some levels taken, for I should have told you that accurate levelling is the basis of all irrigation, and this accuracy is of a kind unknown in ordinary levelling for roads or railroads. The flow of water requires delicate adjustment, and an error of half an inch in a mile is about the maximum that can be accepted.

I have tried to give you some idea of the practice of irrigation from rivers. I have not yet described the third style of irrigation, that from lakes or reservoirs.

A flat country with a feeble slope traversed by no river, and with a very defective rainfall, has a poor chance of being irrigated. But if the country is divided into hill and valley, and if the rain that does fall comes in heavy tropical showers, sites may be found for throwing earthen or masonry embankments across the valleys, and ponding up the rain fall, which again may be discharged from the tank or reservoir thus formed through sluices, and be used for irrigation further down. After all, a tank is a poor substitute for a river, and there have been some notable instances where the cost of the great embankment with its outlet sluices and waste weir to let off surplus water has not been repaid by the revenue derived from the irrigation produced. The calculation is not very difficult to make. Suppose the area of the tank to be a square mile, and the mean depth 35 feet. Probably 20 per cent. of the water or seven feet of depth will be lost in evaporation and percolation between the tank and the field, and a depth of 28 feet be actually employed. If rice is the crop, and it requires to be watered nine inches deep every week for twelve weeks, a depth of nine feet must be given to each field, and if there is only 28 feet of depth available for an area of one square mile, the area that it is possible to water will only be $28 \div 9$, or rather more than three square miles, or three times the area of the tank, and one square mile is drowned in order to irrigate three. Where the tank is shallower, of course, the proportion is different, and the area irrigated may be no larger than the area drowned. Now, if the value of irrigated over unirrigated land is £1 per acre, or £640 per square mile, the revenue of this tank will be about £2,000 per annum ; from this must be paid cost of maintenance, repairs, establishment, etc., say £500. There remains £1,500 interest on the capital spent on the embankment and water courses. If this capital is not more than £30,000, the investment is sufficiently good, considering the additional value of the tank in years of drought. For the value of the tanks in such years may be very great. It is true that if the drought continues long the tank will run dry. In October, 1877, throughout all Southern India there were very few tanks that were not dry. But even then they helped to shorten the famine period. They stored up the rain after it had ceased to fall. They caught up and husbanded the first drops when it began again. A tank-irrigated country is fair to see. One looks down a long valley and sees one embankment after another, each holding up its tank, it may be five miles long, it may be not 500 yards. There they lie like a series of mirrors framed in the ground, and each with its carpet of richest verdure below the embankment.

The tank engineer has plenty to attend to. His enemies are foxes, rats, and porcupines, which are for ever boring holes in his embankments. While he probably looks after half-a-dozen main tanks in a long chain, there may be fifty minor ones looked after only by the peasantry. An unusual rain storm comes on, and these minor tanks fill to overflowing. Bank after bank gives way, and while the rain is still pouring a flood is sweeping down the valley in constantly greater force as the tanks burst. Then is the time of trial for the big Government tanks and their embankments, and happy is the engineer who has made his waste weir about ten times as long as it seems possibly to require, and who has no fear as to the stability of his embankments, his sluices, and long discharging gallery.

There is a class of high-minded patriots who find it their painful duty to decry all that their country has done and is doing in foreign lands. I have often read the wailings of these philosophers over our shortcomings in India. Look, they say, at the plains of Madras. Everywhere are the ruins of embankments, the vestiges of departed glories. How much nobler were these old Brahmans than our degenerate race. Sure enough there are very frequently ruined embankments to be found in Southern India, and the reason is easily explained. A tank, like a human being, has a certain life. Quicker or slower the water that fills it will wash into it sand and mud. Year after year this will go on, and no scouring invention yet has prevented tanks from ultimately becoming filled up with silt. The embankment is raised, and raised again, but at last it is better to abandon the whole work and make a new embankment elsewhere. For it would never pay to dig out the tank by manual labour.

I do not believe there were ever in India at one time so many living tanks holding water and irrigating as there are at present. The ruins we see are the ruins of long centuries, of tanks that were made, that flourished, and that got silted up. But they did not all flourish at once.

I have tried to tell you what irrigation is in general, and sketched to you the busy life of the irrigation engineer. I can assure you it may be a very pleasant life. Those of my audience who have been in Northern India will easily recall the pleasures of camp life in the cold weather, the fresh cool mornings, the early cup of tea, and then into the saddle; the long rides, the variety of interest; the new canal to be picketed out, the centres to be removed from the new bridge, the progress of the brick-burning to be examined, the foundation of the new lock to be got in, the dispute between Pir Bakshh and

Gangadín as to their rights in a watercourse to be settled. Or in Southern India it is a pleasant life in the comfortable canal boat, a floating house with your servants and books around you. Nor is it all work. There is nothing to prevent you taking your dogs and coursing a hare or jackal as you ride along. You may even take your rifle and knock over an antelope, but for my own part I have found it best to work hard and to play hard, and to avoid attempting to combine the work and the play into the same morning. With these preliminary remarks I must now go on to Egypt.

In comparing the countries that played a prominent part in the ancient world with those of modern times, one is forcibly struck with the smallness of the old countries. From the Acropolis at Athens one can see about half of Greece. Rome had obtained a great position ere she ruled half of Italy. There are points in Palestine where the Mediterranean Sea and the desert mountains of Moab are visible at once. The whole land of sacred history lies between these limits. Now our maps are on a different scale. The steppes of Russia, the prairies of America, our own plains of India, comprehend more than all of these classic countries put together. There is only one little country no bigger than it was in the days when Khufu built his Pyramids, 6,000 years ago, which still figures prominently in the world's history. That country is Egypt. Its area is about 10,000 square miles; that of Wales is 7,363 square miles, not much smaller. Why is it that little Egypt still holds so important a place? Firstly, no doubt, on account of its geographical position, commanding the road from the west to the east. But what would Egypt be without the Nile?

Herodotus said long ago, Egypt is the gift of the Nile. Nubar Pasha, the most brilliant of modern Egyptian statesmen, has said the Egyptian question is a question of water. It is quite true. Without the Nile, Egypt would be simply a desert. Were the Nile such a river as some others in the world, such, for instance, as the Mississippi, subject to periods of heavy flood and low supply, at irregular intervals, dependent on uncertain rainfall, its greatest value as a source of irrigation would be lost, for that value is the certainty with which it can be relied on. Year after year it rises at the same period in June, it attains its maximum in September, and begins to diminish, first rapidly, till about the end of December, and then more slowly and steadily until the following June. A late rise is not more than about three weeks behind an early rise, so regularly does it work. From the lowest to the highest gauge is on an average 25½ feet at the first cataract, Assouan. The highest flood is 3½ feet above this average, and this means peril, if not disaster, in the delta. Such floods have happened, four within the last 20 years, the flood of this year being one of the four. The feeblest flood at Assuan attained a level 5½ feet short of the mean. Such a poor flood has happened only once in modern times, in 1877, and the result was more serious in the impossibility of irrigating the Nile valley, than the devastation caused by the most violent excess.

If you will think of the *rôle* played by the Nile in Egypt, you will see the enormous value of this regularity. It does all for Egypt that rain does for England. What would our farmers give here if they could count with absolute certainty that in certain weeks or months it would or would not rain. Such is the certainty with which the Egyptian farmer can count on his irrigation, if it is properly administered.

How does it happen that this river rises and falls with this tide-like regularity? It arises chiefly, I think, from the immense area of its catchment basin, and the small amount of rainfall over the greater part of it. From Cairo to the sources of the Nile is about 34 degrees of latitude, which is just about as far as from Cairo to the White Sea. The two great branches meet at Khartoum, latitude 15°, 1,875 miles from the mouth of the river. The Blue Nile drains a large portion of Abyssinia, and comes down in heavy flood from the mountains in June, bringing with it priceless fertilizing mud. Two hundred miles north of Khartoum the Atbara joins the Nile, also from Abyssinia, a torrent nearly dry in summer, but carrying a great flood during the monsoon. At the same time, the rain has been falling over the basin of the White Nile, but here, owing to the great lakes Victoria and Albert Nyanza (the former alone having an area of 38,000 square miles, or nearly four times the whole size of Egypt), and to the vast marshy tract to the north, it takes longer for the water to flow off, and thus the flood, which would cease in September were it fed from Abyssinia alone, is prolonged into October and November. These great lakes and marshes form the storage reservoirs from which the river draws its main supply during the long dry months until the following May. From Berber, where the Atbara joins the Nile, to the sea is a distance of 1,687 miles, and for all this long distance no tributary joins it. On the contrary, all the forces of evaporation and percolation are at work, water is being greedily taken for irrigation by the dwellers on its banks, and so the great river becomes less and less.

We have no very accurate measurement of the Nile at Khartoum. M. Linant gives the mean flood discharges of the Blue and White Nile at 210,960 and 173,000 cubic feet per second, or altogether 383,960. The mean flood at Cairo is about 280,000 cubic feet per second, and the maximum flood above 400,000. Linant puts down the minimum at Khartoum as 5,480 cubic feet per second for the Blue, and 10,280 cubic feet per second for the White Nile, or 15,760 cubic feet per second in all. The average Low Nile at Cairo is about 14,000 cubic feet per second, but it falls at times to 10,000. The Nile, then, as seen in Egypt, is not a very great river as regards the volume of water it carries, and its size of channel. It is a larger river at Khartoum, 1,700 miles further up. The new-comer standing on the bridge at Cairo is disappointed to see that it is so small, not a quarter of a mile wide. But from the regularity of its rise and fall, and from the richness of its alluvial deposit, it is unrivalled as a source of irrigation.

I have explained the difference between the system of irrigation which employs only the flood waters of the river and that which employs its water at all seasons. Until this century the irrigation of Egypt might have been classed in the former, for although no doubt the water-wheel and the *shadoof* were working all the year round from the earliest days, still irrigation on a large scale was not possible by their means. The irrigation that made Egypt the granary of the ancient world was practised merely during the Nile flood. This system, which is practised still in Upper Egypt, is very complete. Along each edge of the river, and following its course, is an earthern embankment, high enough not to be topped by the highest flood. In Upper Egypt, the valley of which rarely exceeds six miles in width, a series of embankments have been constructed abutting on those along the Nile at the inner ends, and on the ascending sides of the valley on the outer ends. The whole country is thus divided into a series of squares, or rather oblongs, surrounded by embankments on three sides, and by the desert hills on the fourth. In Lower Egypt, where in ancient days there were several branches of the Nile, this system was somewhat modified, but was the same in principle. These oblong areas enclosed in embankments are from about 60,000 to 2,000 or 3,000 acres in extent. I have said that in a deltaic valley like Egypt the slope of the country is away from the river, and not towards it. It is easy, then, when the Nile is low to cut short deep canals in the river banks, which fill as the flood rises, and carry the precious mud-charged water into these great flats. There the water remains for a month or more some three or four feet deep, depositing its mud, and then at the end of the flood it may either be run off direct into the receding river, or cuts may be made in the cross embankments, and the water passed off one flat after another, and finally rejoin the river. In November the waters have passed off, and whenever a man can walk over the mud with a pair of bullocks, it is roughly turned over with a wooden plough, or merely the branch of a tree, and the wheat or barley immediately sown. So soaked is the soil after the flood that the wheat germinates, sprouts, and ripens in April or May without a drop of rain, or any fresh irrigation. You will see how this system might be regulated by giving masonry sluices to these canals, and building similar sluices in the embankments between the basins. In a future lecture I shall tell you how much we have recently done in this way, but strange to say, as far as we can learn the history of classical Egypt from its numerous painted and sculptured temples and tombs, there is no record of any masonry works in connection with their irrigation, and, indeed, there is little to lead one to suppose that the very life of the country depended on it.

From the month of November until the next floods the canals were dry, and there was no irrigation, except what could be done by water-wheels or *Shadoofs* on the bank of the river. And even now, when over half the country there is steady irrigation all the year round, still this flood irrigation is looked on as the chief one. The land tax and the water tax are united in one, and amount sometimes to nearly £2 per acre. He who cannot get irrigation during low Nile is let off nothing; but he whose lands are not covered by the natural flow of the river during the floods, that is, covered without the aid of any water-raising machinery, has his whole land tax remitted, it being considered the right of everyone to obtain a free supply of the flood water. If he does not obtain it then, he is little likely to get water during low Nile, and unwatered land is absolutely sterile.

In other countries we talk of four seasons. In Egypt of two, high Nile and low Nile. The ancient Nilometer at the south end of Roda island just above Cairo is one of the most interesting sights in Egypt. The water enters by a culvert from the river into a well about 18 feet square with a graduated pillar in the centre. On each side of the well is a recess about six feet wide and three feet deep, surmounted by a pointed arch, over which is carved in relief an inscription in Kufu or early Arabic, and a similar inscription is carried all round the four walls, consisting of verses of the Koran relating to the water sent by Allah, the all-merciful, from heaven. A staircase goes down the well, from the steps of which the initiated can read the gauge ; but they are few in number, and the hereditary Sheikh of the Nilometer, whose duty it is to keep the record, is a person of some importance. The Nilometer dates from A.D. 861. It is said to have been formerly covered by a dome, but that no longer exists. The top of the pillar is broken off, and recently searching in the mud at the bottom we found fragments of it, as also of another top which had been added by the French, with its date counting from the Revolution. This had been erected by Napoleon's expedition, and was probably cast down when the French went away. The rise of the Nile is daily chanted through the streets in July, August and September. Everyone knows every day at how many cubits it stands, and what is more remarkable, in Upper Egypt, independent of all telegraphic communication, the peasantry have daily information of the height of the Nile at Assouan, where the other best-known gauge exists. How the information is imparted I cannot tell you, but if you ask a man in Upper Egypt what height the Nile is he will not tell you what it is opposite his village, he has got no gauge to measure ; but he will tell you what it is at Assouan, perhaps 400 miles off. I need hardly tell you, when we English Engineers took the river in hand we established a number of gauges, somewhat more scientific than the venerable Nilometers of Roda and Assouan.

There is no more interesting ceremony in Egypt than the annual cutting of the Khalig, as the old canal is called which flows through Cairo. This is looked on as the emblem that the Nile flood has set in, and that the kindly fruits of the earth may in their season be duly expected. The ceremony takes place when the flood has attained 16 cubits on the Nilometer. This height is reached between the 5th and 15th August. The head of the old Khalig (which is of little use now, and is a sanitary abomination in the city) is to the south of Cairo. The water enters a channel some 30 feet wide, with a high wall on its left, and a sloping bank on its right or southern flank, and passes under the pointed arch of an old stone bridge. The canal is cleared, so that the water would flow in at a gauge of about $14\frac{1}{2}$ cubits, but an earthern bank is thrown across it about four feet higher.

Days before the opening, preparations are being made for the festival. Tents with innumerable lamps are placed along the wall on the one side. Frames for all manner of fireworks are erected on the sand bank on the other side. All the notables of Cairo are there in full uniform or canonicals. The Viceroy himself, or his representative. The Sheikh-ul-Islam, the Sheikh-es-Sadát, the Sheikh-el-Bekri, and all the Ulema of the Azhar, the Cabinet Ministers and Under-secretaries, the Sirdar and his staff, the Judges, the Financiers.

The Egyptian troops are turned out, salutes are fired, and about 8 o'clock in the night, when the Nile has attained the proper height, all assemble under the gaily-lighted tents, and the street is lined with harem carriages crammed full of closely-veiled figures come to see what they can from the windows of their broughams. The populace are out on the bridge and the opposite bank, shouting, yelling and dancing wildly between the frames of whizzing, whirling, cracking fireworks. Out in the river just opposite the mouth of the canal, a ship painted somewhat to look like a sea-going craft is moored, also gaily illumined, and bristling with fireworks. This has been towed into position during the day, and is a memorial of the time when the great Republic of Venice used to send an envoy to be present at the ceremony. It is altogether an impressive sight. Overhead the clear star-lit sky. Around the brightly-lighted tents, and gay uniforms, the fireworks, the torches, the excited crowd ; and looking over the wall down on the rushing muddy waters you soon see brown naked figures plunging in, and waist-deep cutting away with hoes or with their hands at the earthen embankment that blocks the canal mouth. The residents of Cairo by long usage were absolved from working in any agriculture corvée, but this one service they are required freely to render the State. They must furnish the working party that cuts the Khalig. I do not think it is looked on by anyone as an onerous task. Cairo contains some 11,000 Jews, and as the law stands, the faithful Moslems are to cut the Khalig one year, the Jews the next year. Only should the Nile rise to 16 cubits on a Saturday, the Jewish Sabbath, even should it be the turn of the Jews to furnish the labour that year, the kindly Muhammedan law lets them off, so as not to interfere with their religious prejudices.

Long before midnight the fireworks have gone out, and the grandees gone to bed. But the people keep up the fun all night, and in the morning by half-past seven everyone has returned. Little of the embankment is now left uncut, a few more strokes of the big hoes will do it, and the brown skins and the brown water reflect the bright sunlight from above. Then the Sheikh-ul-Islam solemnly thanks the Almighty, Allah, the all-powerful, the all-merciful. He implores His blessing on the rising Nile, and at a signal the bank is cut, the waters rush in, and a crowd of men swim in with them down the canal. Then the President of the council scatters a bag of piastres among the men in the water, and the ceremony is at an end. I have witnessed the cutting of the Khalig several times, and always with pleasure. It is one of the few religious rites I have shared in where the Christian and the Moslem can equally unite in thanksgiving to heaven for the fruits of the field. There is a pretty legend worth telling you of the cutting of the Khalig, when Amru the Mahommedan Khalif took Cairo, A.D. 640. The ceremony was of much earlier date, but in Pagan times it was the rule that a virgin should be sacrificed to propitiate the god of the river. When the season came round accordingly Amru was called upon to sacrifice the maiden, but he sternly refused. That year the Nile flood was a failure. You can fancy how the indignant heathen population must have raged at the invader and said :—We warned you what would happen if you would not sacrifice the girl. Surely even Amru's wild Arab soldiers must have had their faith sorely tried, and they must have felt puzzled as to whether in this strange new country, with all these demon-built pyramids and obelisks, temples and sphinxes, it might not be as well to make friends with the local gods. Again the Nile flood came round. This time, surely, they said to Amru you will sacrifice the girl. But he was obdurate. The people rose in rebellion. So he took a bit of paper, and wrote on it. "Oh Nile, if you rise of your own accord, rise or not as you like. I am not going to sacrifice a girl's life to you. But if, as I believe, you rise at Allah's will, that must be right whether you rise or not." The legend says the stout old soldier threw his paper into the river, which went on rising exactly as they wished, and no more girls were sacrificed, but to this day a pillar of earth is left to be washed away by the canal, which is called the *bint*, or the girl.

Until this century the irrigation of Egypt was much as I have described. Advantage was taken of the flood, but the low Nile from November to July was allowed to flow to the sea with no other purpose than that very important one of forming the great highway to the country.

In my next two lectures I will speak of what has been done to improve the irrigation of Egypt during the present century.

LECTURE II.

With this century there appeared a very striking figure in Egyptian history. Muhammed Ali Pasha was no unworthy contemporary of Napoleon and Wellington. He came as a captain of Albanian infantry from Turkey about the time of the French invasion, and before many years had made himself master of the country, yielding only nominal respect to his Suzerain Lord on the Bosphorus. This is no place to go into the history of Muhammed Ali's career. He was not more unscrupulous than Napoleon. In some respects he was not unlike his co-religionist Hyder Ali, who had been giving us such trouble in Southern India when he, Muhammed Ali, was a young man. He had no education to speak of, talked nothing but Turkish, never even learned Arabic, but he was a born ruler, of strong common sense and shrewdness. He soon recognized that with such a climate and such a soil, with a teeming population, and the markets of Europe so near, they might produce something in Egypt more profitable than wheat and maize. Cotton and sugar cane would fetch far higher prices. But they could only be grown when the Nile was low, and they must be watered at all seasons. Here was a fresh departure: perennial irrigation instead of only flood irrigation. How was it to be managed?

I said in my last lecture the Nile rises about 25½ feet. A canal, then, that runs 12 feet deep during flood, has its bed high and dry 13½ feet above water surface when the river is at its lowest. Either the water in the Nile must be raised, or the beds of the canals must be lowered to enable the one to flow into the other. Muhammed Ali began by lowering the beds of the canals of Lower Egypt. This was an enormous work considering the mileage of these canals, and as they had been laid out to suit the wishes of private individuals, of Turkish pashas, at times of village communities, but never on really scientific principles, and as those who had to excavate them to this great depth had only the slightest knowledge of levelling, the inevitable result followed—the deep channel got filled with mud during the first flood, and all the excavation had to be done over again. This mattered little to a despot like Muhammed Ali. If his fellahs were not fighting his battles in Arabia or Syria, they might as well be digging canals. No one dreamed of paying them. The *Kourbash* was freely applied to the soles of their feet if they attempted to run away, and somehow the work was done.

But the system had another disadvantage. As I have said, the levelling of the canal beds was very imperfect. It did not follow that if water entered at the head it would flow onward. Then, as the river daily fell, of course the water in the canal fell, till at last, since they were never dug deep enough to draw water from the very bottom of the river, the canals would run dry altogether in the month of June, precisely the month of the greatest heat, when water was more than ever necessary to the life of the cotton plant. And so large tracts of cotton which had been sown and irrigated, weeded and nurtured for, perhaps, three months, perished unfruitful for want of water in the fourth.

It was then that some one, probably one of his French staff, suggested to Muhammed Ali that he should control the Nile with a dam or *barrage* at the head of the delta, and the result was a very costly and imposing work, which it took long years and untold wealth to construct, which was no sooner finished than it was condemned, and the restoration of which to being a work of first-class importance and utility has been the proudest achievement of the English engineers in Egypt.

The word *barrage* is the French for a dam or weir over a river—a bar—and the Great Nile *barrage* north of Cairo has the same functions to perform as any of the familiar mill dams in this country which raise the surface of the river and divert it into the mill lead. The designing of a dam or weir over a large river is a complicated problem. It is necessary first to know what volume is carried by the river at all seasons, and what volume it is desired to abstract from the river. If the volume required to be drawn off the river is greater than its normal discharge during a certain portion of the year, then the dam should be raised high enough to pond up the surplus water at the seasons of plenty, and to form a reservoir. By such dams, I described in my last lecture, tank or reservoir irrigation is effected. But generally speaking, water storage is not a desideratum, with irrigation dams at least, and the conditions of the problem are more than satisfied when the water surface of the river at its lowest is held up to the level of flood water surface. And this holding up of the water may be done in more ways than one. It may either be by simply building a strong wall of masonry across the river to the required height and furnishing it with a long masonry apron or floor, and this is what is commonly known as a weir. It is the simplest form of dam, and has many virtues, but, of course, it cannot be taken out of the way during floods, and, therefore, does not meet the conditions of many rivers. The flood discharge of a river is often 50 times that of its low supply. It is never desirable to raise the surface of flood supply, but the reverse. Generally we know that if the flood surface is raised above a certain point inundation will be produced. And in order to minimize the effect of the fixed weir in raising the flood water surface, we must lengthen its crest, so as to spread the flood over a much greater width than it would naturally have at the point of obstruction. For remembering that it is the product of the width of the stream, by its depth, by its velocity, that produces the volume discharged, if we increase the width, the depth or height above, the weir becomes reduced. The velocity, too, is always greater over a weir, and that also helps to keep down the flood surface level.

That increased velocity, too, must be calculated lest it be too great for the building materials at our disposal. A higher velocity may be allowed to fall on a granite floor than on one of sandstone or brickwork.

It may be impossible to design a fixed weir to meet all the required conditions, an upstream water surface not too high, a velocity not too great, and if so, we must abandon the weir design and raise the water surface during the low season by some form of obstruction which may be removed during flood; and this brings us to the more complicated forms of dam.

I shall not attempt to describe to-night the various types of moveable dam, of which I think the highest and most ingenious development is to be found on the river Seine. In Egypt there could never have been any doubt that the weir with a fixed height of crest was inapplicable. A raising of flood level would at once inundate Cairo. The Great Nile barrage, therefore, which was designed by M. Mougel, an engineer of the Ponts et Chaussées in France, consists of two bridges spanning the two main branches of the river at the point where they separate (*Plate* II.). The bridge over the Rosetta branch consisted of 61, and that over the Damietta branch of 71 arches, each five mètres, or 16·4 feet span. They were designed to be fitted with iron gates meant to be self-acting, but they were not a success, and were only put into place on the Rosetta branch. These gates were intended to hold the Nile supply up to the height of 4·5 mètres, or 14·76 feet. The floors of the arches were stone inverts. The height of pier from edge of flooring to spring of arch was 28·7 feet, and this spring of the arch might be taken as the height of maximum flood.

There can be no doubt Mougel Bey must have had a hard task in directing these works. The labour was forced, whole battalions of soldiers being sent to the work one day, and withdrawn the next. There is no want of good lime and good stone in the country, but only those who have worked with an Eastern people can conceive the want of method and arrangement in maintaining a regular supply of these materials; only with such experience can it be conceived how much swindling must have gone on, how much rubbish must have been mixed with the lime, how much scamped sham work put into the masonry, as we found when we came to examine it. It is told that during the reign of Abbas Pasha I., as cold-blooded and barbarous a ruffian as ever ruled in Egypt, stone one day fell short, and he sent for Mougel and ordered him to pull down the pyramids of Giseh to supply the deficiency. There was no use remonstrating with him on the vandalism of the act. What does a Turk care for antiquities! It was not safe to thwart his imperious ideas. It might have cost Mougel his life. Was he then to be handed down to the execration of posterity, he a Parisian of culture, the countryman of Champollion and Mariette? His clever French wits helped him out of the difficulty. He told Abbas that, of course, his will should be done, but he ought to know beforehand that with such infernal skill had those old Pagans built their pyramids, that it would be cheaper to quarry the stone from the hill side than to try to dismantle them.

Fitfully the work progressed, but it was at last declared to be finished in 1861, and a brilliant inauguration took place.

It was intended that all the irrigation of Lower Egypt should have its origin at the barrage, that is, that instead of having numerous canals leaving the river on both sides of the two branches all the way to the sea, there should be three main canals, taking their water from just above the barrage, one to the right or east end of the Damietta branch, intended to water all the eastern delta, one between the two branches to water the central delta, one to the left or west end of the Rosetta branch to water the western delta, known as the province of Behera, right away to Alexandria. These three canals were an essential part of the barrage project. There was no use of raising the water if it was not to be turned into the canals. The centre canal was more or less finished, not very well done, but sufficiently well to be a useful work to this day. The eastern canal was dug for some five miles. There it came to the edge of the property of an old Turkish lady—someone of importance's grandmother. She refused to let her land be cut up by a canal, and the project stopped then and there, one-third of the delta being thus thrown out. The western canal was dug, but within its first 50 miles it passes through a good deal of desert sand, and sand drifted into it. Corvées of 20,000 men used to be forced to clear it year after year. But they got tired of it, substituted for it two immense pumping establishments, and when I went to Egypt in 1883 this canal was practically abandoned. Perhaps more might have been made of it, and the old grandmother princess on the eastern canal might have been got out of the way, but the barrage itself was condemned by this time, and what was the good of keeping up these canals? In 1863, the gates of the Rosetta branch barrage were closed for the first time, but only to be re-opened at once as a settlement of the masonry occurred. The experiment was repeated year after year, till in 1867 a very alarming settlement took place. In fact, the Rosetta barrage was cracked right across from foundation to top, about nine arches from its left end. An immense coffer-dam was then erected covering 11 arches about the crack, but the barrage was never trusted, and though the gates were partially closed on the Rosetta side, the water surface was not raised more than about a mètre, and very little service was done by it. The heavy endless work of the corvée went on. The situation grew worse and worse. A very distinguished English engineer was invited by the Khedive Ismail Pasha to examine the work. He did so, and said it could be put into working order for $1\frac{1}{4}$ million sterling. But that profligate ruler who could afford to throw away millions to gratify his extravagant whims could not sanction such an outlay as this for such an important work. Its success was not believed in. A committee in 1881 reported that the yearly increasing burden of the corvée could be borne no longer. As all were convinced that the barrage was of no good, attention was turned to a rival project to establish a huge system of pumps worked by steam power, raising the water from the river even at low supply, and discharging it into shallow canals; and negotiations were on foot with a foreign company to carry out this plan. Such was the state of Egyptian irrigation when Arabi's revolt took place in 1882. The whole country was groaning under its burdens. The rich even were feeling the pressure, for the taxation was heavy, cotton had gone down in price, water was more difficult to get. Happy the reformer who steps in just when things are at their worst, when the people have lost hope of helping themselves. Happy the reformer whose work is of so special a nature that everyone all round him does not pester him with advice and suggestions. Happy the reformer that has a Governor or Government behind him with a backbone, and a will, and that sees he is left to carry out his views. Such happiness, such very unusual good fortune, fell to the lot of myself and the band of my Anglo-Indian fellow workers, who have been at work in Egypt since 1883.

I landed at Alexandria on the 3rd of May, and the next day was presented with a carefully-written pamphlet, trying to prove that it would be only a waste of money to attempt anything at the barrage, and that Government must adopt the alternative project I have mentioned of erecting a huge system of pumps with which to fill the canals. This project had already been put into execution in the western province of Behera, where, as I have said, two great pumping stations had been erected ; and the Government had entered into a contract with a company owning these pumps to pay them annually a sum equivalent to from £60,000 to £70,000. It was proposed to extend this system to all the rest of the delta, at an initial cost of £700,000, and an annual outlay of £250,000, and it was claimed for this system that (1), it would be much more certain than using the barrage ; (2), that it would deliver water on to the surface of the land without any further pumping on the part of the cultivator ; and (3), that it would avoid the expense of silt-clearing or dredging. I was asked to give my opinion at once on this matter, and the magnitude of it somewhat took away my breath. I was bound to accept what everyone said, that the barrage was a failure, but would it not be cheaper to build a new one than to adopt the pumping alternative? Was it politic to commit the very life of the country to the risk of some day a European war cutting off the supply of coals on which depended the pumps? I did not find the water in Behera delivered on to the land. On the contrary, the province was filled with steam pumps. Nor did I find that dredging was unknown there. On the contrary, it was costing about £5,000 to keep the Mahmudieh canal open for navigation.

I refused, then, to give my opinion on the subject, and spent the summer of 1883 in travelling about, and trying to learn the existing state of affairs.

In now going on to relate what we have been doing in Egypt, the personal element must perforce come in, and I must be forgiven if I use too often the first personal pronoun. In no sham modesty, but with perfect sincerity, I assure you that I could have done nothing in Egypt had I not been supported and surrounded by such a staff of colleagues as surely no chief ever possessed. Men who knew their work, and did it. Whose loyalty and energy I could absolutely count on. "Who scorned delights and led laborious days," not in search of fame, but in simple discharge of duty, of more than duty. Ask whom you will of those who have been of late years in Egypt, and they will tell you that no body of men have done so much to make the English name honoured as the irrigation officers. It was they who have been toiling out in the provinces through hot weather and cold, badly lodged, badly fed, denied domestic comforts, being constantly absent from home. All this time I have been in my comfortable office in Cairo, with all the luxuries of civilization about me. They have really done the work, while mine has been the honour of sharing the responsibility. My function has been merely to fight their battles at headquarters, and to back them up through thick and thin, and insist that they were always right—in short to keep the wheels oiled. I must give you their names now, and if later on I seem to take to myself too much credit, I beg of you to understand that such is far from my intention.

The first to join me in Egypt from India was Colonel, then Major, Justin Ross, of our Corps, who had worked with me through many a hot day. I do not believe there is anyone in the world that knows more about irrigation than he does. When later on I was given charge of all the other public works in Egypt, he was made Inspector-General of Irrigation. He has now resigned with health shattered in the service, but he has left a splendid monument behind him in the remodelled irrigation of all Upper Egypt.

Colonel Ross was soon followed by Mr. Willcocks, of whom I shall have often to speak. He is the author of an excellent book on Egypt irrigation, from which I have largely borrowed. Then came Major Brown, of our Corps, who has been contented to live with wife and children in a wretched Arab town, Minieh, in Upper Egypt, for nine continuous hot summers; and Mr. Foster. Then when we got money really to do work I was joined by Colonel, then Major, Western, of our Corps, also a tried Indian friend, and by Mr. Reid, a most accomplished engineer from the Punjab. Lastly came another Indian friend, Mr. Garstin, who has now succeeded me in Egypt. To these seven officers it is due that the irrigation of Egypt has made the most enormous progress. Colonels Western and Ross, and Mr. Reid have all left with the decoration of St. Michael and St. George. The other four officers are still in the Egyptian service.

Mr. Willcocks took up his residence at the barrage about January, 1884. We had a good look at the work. We remarked that the Damietta branch barrage had never been tested at all, for gates had never been fitted into it. We examined the great cracks through two or three of the arches of the Rosetta barrage where the work had recently been broken in two, deflected from its long straight line. There seemed to have been no recent settlement. About 48 of the 61 arches seemed sound enough. The case did not seem so hopeless. And yet everyone warned us not to attempt to do anything to the barrage, one well-known English engineer assuring me of the startling fact that he had himself seen a man dive into the muddy water above the bridge, disappear from sight, pass under the foundations and come out all right below. We thought—the work is of no good now. If we put pressure on it, and it gives way, Egypt will be none the worse off. If it does not give way, Egypt will be vastly the gainer. *L'audace, toujours l'audace* is not a bad motto sometimes. Let us at least give it a trial. Willcocks set about placing a little tell-tale patch of Portland cement on every crack he could see, and he put a number on each. £25,600 were spent in strengthening the rough stone apron down-stream of the work, in replacing old timber by new, etc., and we resolved that the gauge up-stream of the barrage should not be allowed to fall below 13·00 mètres above sea level. Previous to this year it had never stood higher than 12·00 mètres in the summer months. At the end of January the river in its natural flow had come down to 13 mètres. Then the anxious work began. Daily the river fell. Daily Willcocks closed another gate or half-gate of the barrage. The up-stream surface remained at 13 mètres. The down-stream surface kept falling, and daily the pressure upon the work became greater. Daily the cracks were watched. If they had opened out across the fresh-placed tell-tales it would have indicated fresh settlement. As long as there was no indication of this we were safe enough. So passed the season. In June our up-stream surface was still 13·00. The down-stream had fallen to 10·80, or there was a pressure of 2·20 mètres, or seven feet two inches, on the despised barrage, and canals previously dry at this season had more than three feet of water flowing in them. Our works so far had escaped much attention. But the keen cotton merchants of Alexandria were not long in seeing what was happening. Previous to 1884, the cotton crop had not exceeded 130,000 tons. That year it produced 160,000 tons. The price of cotton at that time was about £55 per ton. The increase of the crop was 30,000 tons, worth £1,650,000, not a bad return for £25,000 and the honest six months' work Willcocks had bestowed on the barrage.

The Alexandria Chamber of Commerce sent us a warm letter of thanks for our success.

In 1885 we pursued the same course as in the preceding year, and spent £18,246 in strengthening and patching up the work. That year and ever after we put on a pressure of not less than three mètres, or 9 feet 10 inches. In 1891 we raised to 11 feet 4 inches, and this year about 12 feet 10 inches has been held up. Thirteen feet is all that is ever likely to be required of the barrage. Those were anxious days for Egypt. Our own chivalrous Gordon had gone up to Khartoum, faced fearful odds there through 1884, and perished in January, 1885. Troops were moving in great numbers up the river; and while Egypt's external relations seemed about as bad as could be, the Soudan abandoned, Suakim hard pressed, Khartoum besieged, the internal relations were little better. An enormous public debt was crushing the country. An indemnity of five millions sterling had been promised to the foreigners who had been burnt out by the fire at Alexandria; the Arabi rebellion, of course, had cost a great deal of money; cholera had raged through the land in 1883, cutting off thousands and stopping foreign commerce. A great international conference was held in London in 1885. It was agreed that merely to meet the immediate wants of Egypt a new loan of eight millions must be raised forthwith, and then Lord Cromer (or Sir Evelyn Baring as he is better known), the Consul-General in Egypt, said another million must be added to be spent on works of irrigation. To many this counsel seemed nothing but the height of folly. Egypt owed its disasters to reckless extravagant borrowing. Now when it was at its lowest, was it to go on borrowing, not to meet engagements, but to construct new public works? Fortunate was it that Egypt had then so strong a Consul-General, so large-minded a statesman, so sound a financier, one who refused to be panic-struck, and with a cool head discriminated between borrowing money to waste on tomfoolery and borrowing to execute reproductive work. A very distinguished member of our English Treasury told me two years ago that he had hotly opposed Lord Cromer at this conference, and had protested earnestly against the irrigation loan; but he added he knew now that he had been wrong and Lord Cromer right, and that it was all due to the good work of the irrigation officers that it was so.

With this million at our disposal our hopes arose in Egypt, and we had to work hard to determine how it was to be spent. Two seasons' work on the barrage had convinced us that it was not so bad as it had been called, and that in any case it must be repaired or re-built, and the rival scheme of huge pumping stations must be abandoned. The barrage was then our first object of solicitude, and Col. Western and Mr. Reid, who arrived from India in September, 1885, devoted their whole attention to it. The problem was a difficult one. It would have been much easier if we had been called upon to build a new dam in a country where irrigation was to be introduced when the dam was finished. We should have known exactly what we were dealing with, while here we knew most imperfectly, and could not find out without laying bare foundations far under water level, in itself a dangerous operation. We would have designed a new dam according to the best of our abilities, while here we had to adapt our design to an existing dam containing many features of which we disapproved. Lastly, we would not have begun irrigating until the work was finished. Here the irrigation, with all the stimulus we had given it in 1884, must go on. Col. Western used to protest when to get at the foundations he wished to have as little head of water as possible to deal with, and I insisted on his maintaining the maximum head of water possible, that is 13 mètres above sea level. I knew that the irrigation effected by this extra head would in one season be worth all the money we were going to spend altogether on the barrage. I admit it greatly increased the difficulty and the risk of failure. But again, *l'audace, toujours l'audace!* I used to tell Western you might as well ask a doctor to kill a patient in order to put his inside all right and start him again, as to ask me to kill the irrigation of Egypt in order to restore it better than ever five years hence. The patient we must not kill. The irrigation must not be checked, if for no other reason, for the political reason alone, that the people would have risen in revolt, and there would have been an end of all barrage repairs.

Col. Western and Mr. Reid arrived in 1885, when the river was in full flood. It was determined in 1886 to make a trial at laying bare the foundations, and that this trial should be at the west end of the Rosetta barrage, where, as I have already said, the arches were badly cracked. On the 24th March we began by running out embankments some distance up-stream and down-stream of the barrage, extending out so as to cover 20 arches, where the ends were brought round to meet. Up-stream the water was about 18 feet deep; down-stream about nine feet. These embankments took about six weeks to finish. Then the water was pumped out of the chamber thus enclosed, and for the first time we saw what work we were dealing with, and the more we saw it the less we liked it. It was, however, a great satisfaction to find that with earthen banks alone, and without excessive steam pumping, we could lay bare the river bed, and keep it dry.

The barrage is built on nothing more solid than alternate beds of fine river sand and alluvial mud. This is not a very good foundation for an ordinary bridge, but when the bridge was also to be a dam with a head of 13 feet more water on the up stream than on the down stream side there arises a constant tendency for the water to percolate under the foundations, and establish a uniform level. Evidently this percolation had washed out the soil and caused the settlement and great cracks in the arches of the Rosetta barrage. The problem was to place across the river an impermeable bar round which the water would not travel. Previous to 1882 it had been proposed to do this by sinking a curtain wall 60 feet deep, either just above or just below the barrage, as shown on *Plate* III. Had we been able to count on rock or very solid clay at this depth, or had we been building an entirely new barrage, we should probably have adopted this design; but we knew the subsoil was no better than the upper soil, and we dreaded the effect of digging such a deep hole close to the barrage, lest we should bring it all to ruin. We resolved, therefore, to follow the system introduced and employed with such success by Sir A. Cotton in India, namely, of shallow foundations widely spread out. There was no question about this being the safest and the easiest form of construction, and if we could succeed in making our whole broad floor into one homogeneous mass, the water percolating from up-stream to down-stream would have to travel, perhaps, as far under the masonry as if the foundations were narrow and deep. You will understand what I mean by referring *Plates* III. and IV.

As originally designed, the flooring of the barrage was 111·50 feet wide, terminating on each face with a row of short, badly-driven piles. The percolation had to trickle under this width. The proposed addition of a deep curtain wall would have forced the water to creep under an additional horizontal distance of 26¼ feet, and under a vertical distance of nearly 60 feet. The standard design we adopted required the water first to pass under a 16 feet screen of sheet piling and a horizontal distance of 223 feet. This was the general design, and nowhere was the floor shorter, but frequently it was made considerably longer, and heavy pitching was added both up and down-stream. The old flooring directly under the arches was inverted, the rise of arch being about four feet. The new flooring was horizontal, the upper surface coinciding with the former spring of arch. This was equivalent to covering the whole of the old flooring with a layer of the best Portland cement concrete, consisting of five parts of broken limestone, 1½ of sharp desert sand, and one of Portland cement; and upon this concrete was laid down-stream of the gates an ashlar floor of heavy blocks. Directly under the bridge, where the action was severest, these blocks were of a very close-grained trachyte, brought from Trieste. The apron beyond that was of good ashlar limestone. Up-stream of the gates the masonry covering to the concrete was of the same thickness, but it was of rubble work, set in mortar of one Portland cement to two of sand. The season of 1886 was purely experimental, but the floorings under six arches were successfully covered as described above, and then we had to clear away our embankments and prepare for the coming floods in July.

We could never have closed for a whole season the whole of either branch. We resolved, therefore, to do about one-half of each of the two barrages each season, and this inferred four years' work. Owing to the height of the river, we could not begin generally throwing out our embankments till the end of November. We could not complete them, so as to form a coffer dam round the half barrage, before the middle of February, and it took three weeks longer before the water inside could be pumped out, and we could have a dry floor to work on.

You will understand the very great importance of keeping these embankments tight. Not only did we have double banks right round, but inside we used to divide up the space as it were by bulkheads, consisting of three banks parallel to the axis of the stream. From the time the embankments began in November till we had got the floorings dry in March work was carried on by day without a break, week day and Sunday alike; from that time onwards to the end of June the work went on without interruption day and night—the night work being carried out by the light of eight electrical arc lamps, each of 2,000 candle power. Very little actual building was done during the night, but a great deal of carriage of materials to site for next day's work, embankments were maintained, pumping of course went on, and from 800 to 1,200 men were thus kept usefully employed under one assistant engineer and one head overseer.

At the end of June we knew the flood must come, and everything had to be cleared out of the bed of the river, and cuts made in the embankments, so that they might readily breach. On the afternoon of the 1st July, 1887, we had removed the last piece of machinery from the flooring. Before daylight next morning the rising flood had covered all that had been done.

In 1887 we finished the western half of the Rosetta barrage; in 1888 the eastern half of the Damietta; in 1889 we returned to the Rosetta, and completed the eastern half. We were lucky so far that season that we could begin the embankments as early as the 2nd November, and fortunate it was that we could, for we found, for 320 feet from the river's bank up-stream of the barrage, we had an average depth of 40 feet, and for 80 feet we had to work in water not less than 50 feet deep.

You may suppose it was a long time before visible progress could be made in tipping light soil into this deep water. It assumed a very flat slope, the bed being appreciably raised 100 yards off our banks, so we found it necessary to make large use of sandbags. Some 90,000 were employed on that season's work. Fortunately we had the parapets of condemned fortifications to draw on, and patiently and steadily the work proceeded. But owing to the great cost of this bank we resolved to trust to one alone, instead of two parallel banks, and this one earthen bank successfully sustained a head of 17 feet during the four months of our operations.

It would take much too long a time if I were to try to tell you the various incidents and accidents that occurred during these four years. Nor am I competent to do so. Mr. Reid was never off his works, and seemed everywhere on his works. At times there were as many as 10,000 native labourers. There were Greeks, Maltese, Italian and French artisans. The work was done through the intervention of innumerable small contractors or gangers. The material department alone was a big one, and Mr. Reid insisted on the most perfect order in stacking his materials. Large use was made of light railways and trucks propelled by men, which were laid along all the embankments. Some new difficulty was always arising. One morning Mr. Reid was working with some 500 men under the great lock wall at the west end of the Rosetta barrage. They were preparing to lay a bed of concrete really under the old foundations, which were found to be eight feet shallower than those of the bridge. Suddenly just over their heads a horizontal crack ran rapidly along the wall, and it showed signs of heeling over altogether. Mr. Reid at once knocked off work, flooded the whole area with about six feet depth of water to restore stability, and then leisurely bit by bit shut off a small area and got in his concrete, never exposing more than a few square yards at a time A constant difficulty was the powerful springs of water that kept bubbling up through the old masonry, and beyond it at the heads of the old piles. When these springs came up between stones, or where, apparently with intention, a brick had been left out, it was easy to close them with a wad of tow and tapered wooden plug. But when they spouted out water and black mud to a height of two feet or more at the heads of the old piles, or beyond the masonry altogether, it was a more difficult business. They were first enclosed in a ring bank of perhaps six feet diameter, within which the water was allowed to rise. Just where the spring was rising inside this bank an iron pipe was fixed vertically and all round it Portland cement concrete was tightly rammed, til at last all the water was confined inside the pipe. Finally on thi was screwed a tight cap, and the pipe was then regularly built int the masonry. These pipes varied from 6-inch to ½-inch diameter according to the force of the spring, and many hundreds were em ployed. Sometimes as many as 15 12-inch to 10-inch steam pump had to be kept going.

The barrage has been furnished with new iron gates, working vertically in carefully-planed cast-iron grooves. As the height t be closed is four mètres, or 13 feet, and the opening, inclusive o grooves, is 18 feet, it would have been unwieldy to have employe only one gate for each opening, and so two have been erected, eac $18 \times 6{\cdot}5$ feet, one fitting on the top of the other, but in separat grooves, so that either can be raised independently of the other Along the whole face of the bridge, resting on the pier heads an directly above these grooves, is laid a tramway bearing a very in geniously-designed travelling winch, by means of which the gate can be raised or lowered. On the 16th June, 1890, Mr. Reid coul report that the work was finished up to water surface line. Th barrage has since gone through two seasons of low Nile, and ha shown no signs of failure. As it is, during May and June the whol water of the Nile is so diverted into the three great canals that me and women may be seen wading across the two branches of the rive just down stream of the works; and this they often prefer doing t paying a halfpenny toll for crossing the bridge. The percolation i practically nothing.

The average cotton crop for the five years ending 1884 amounte to 123,000 tons. Now, from 190,000 to 200,000 tons may safely b counted on. The price of cotton is now very low, but if it does no exceed 4d. a lb., or £36 10s. 0d. per ton, this means an increased production of say 70,000 tons per annum, or £2,555,000, which is not a bad interest on a total capital expended of about £460,000.

From these figures you will see how very great are the interests involved, and how essential it is that the works should always remain in the hands of competent engineers. Whether it is the least probable that for many a day to come such engineers will ever be found among the natives of Egypt it is not for me here to give an opinion.

I shall continue in my next lecture the account of what we have been doing to the irrigation works of Egypt.

LECTURE III.

In my last lecture I described briefly the work that we had carried out at the Great Nile barrage to adapt it for its functions. In this, my last lecture, I shall tell you about some of the other principal works we have undertaken.

Closely connected with the barrages, and carried out under Mr. Reid's directions, were two very difficult works, the building of a lock to allow of navigation in the great central canal between the barrages, and the building of the head sluices and lock for the great eastern canal. As I have already told you, the central canal had been working successfully for many years, but the entrance lock had never been completed, and to carry out this work without closing the canal was a very difficult operation. It was successfully done at the cost of £15,222. The lock is $50 \times 8\frac{1}{2}$ mètres, or 160×28 feet. The head sluices of the great canal at the east end of the Damietta barrage are six in number, each five mètres span, or exactly the same as the barrage; while the lock alongside, like the others, is $50 \times 8\frac{1}{2}$ mètres. The difficulty here was the extremely unsatisfactory nature of the subsoil. The work was built following the common Indian plan on 134 brick cylinders, from $2\frac{1}{2}$ to $4\frac{1}{2}$ mètres external diameter, or four-sided blocks generally $3\frac{1}{2} \times 2\frac{1}{2}$ mètres. All were hollow inside, and sunk by dredgers to a depth of 18 feet below the bed of the canal. They were then filled with concrete, the spaces between them closed by piles. Their upper surfaces were from three feet to eight feet below the canal bed, and upon this was laid a bed of concrete and masonry. The work cost altogether £51,664, and has been a complete success.

I have thought it best in relating the principal works in which the English irrigation engineers have been employed in Egypt not to attempt any chronological order, but to describe them one by one. The restoration of the barrage and the diversion into the three great canals of the whole low Nile supply would have two certain results, which it was our duty to prevent: first, the water being withdrawn from the river in summer would practically destroy all the navigation on the two branches north of the barrage for about four months every year; and secondly, the fresh water having been withdrawn, the salt water would inevitably flow in, and many towns along the river banks towards the sea would lose their supply of sweet drinking water. Even Alexandria itself was affected. For the great Behera canal having been abandoned, Alexandria drew its water supply from the Mahmudieh canal, which was fed by the river at Atfeh, about 30 miles from the sea, and if there was no fresh water to come down, we might be sure the salt water would flow up more than 30 miles.

These great evils had to be met with out of our million. To replace the two dried up branches of the river, it was necessary to fix on two main lines of canals, and to make them navigable by building locks and swing bridges. The great line down the centre of the delta known as the Menoufia canal, at the head of which, as I have told you, we had built a lock, and one of its branches, called the Baguria canal, were chosen to replace the Rosetta branch. Four large locks 160×28 feet were built on this line, so that boats from Cairo on the south could pass in at the barrage, follow this canal for 60 miles, lock back into the river at a point where the bed was below sea level and there would always be deep water, pass down to Atfeh, where a lock already existed into the Mahmudieh canal, and follow it for 45 miles to Alexandria. To replace the Damietta branch we fixed on the great new canal to be dug at the east end of the barrage. This, which has been called the Tewfikieh canal, is 23 miles long from its head to where it tails into a system of old canals, which have had to be widened and supplied with three locks, the last tailing back into the Nile just below the town of Mansourah. In these upper 23 miles, the canal has a bed width of 85 feet, and an average depth of excavation of from 15 to 20 feet, so that it involved nearly eight million cubic yards of earthwork, and cost £210,000.

To supply the towns along the river with drinking water, we had to see that there were canals parallel to it, and at no great distance. This was generally the case, but we had to make three miles of new canal down to Damietta, where we built a cistern capable of holding a six weeks' supply of fresh water, and for Rosetta we made an entirely new canal. It was 24 miles long, and water was admitted into it ninety days after the digging began. To keep the salt water from coming up the river to Atfeh, and so getting into the Mahmudieh canal and vitiating the fresh-water supply of Alexandria, there was only one thing to do before we had completely restored the great western or Behera canal. It was to throw an embankment right across the Nile a few miles above Rosetta, and so prevent fresh water from getting out and salt from getting in. This was a new departure in Egypt, a kind of contempt cast on the ancient river which the natives did not half relish. But it was done by Mr. Foster every year in February and March from 1885 to 1890 inclusive; and every year it was breached and swept away by the rising flood in July. It cost annually from £11,000 to £8,000. It was only a few feet thick, but it served to hold up the fresh water a few inches above the salt water, and standing in it I have found green sea water on the down-stream side and porpoises swimming in it, while on the up-stream there was good drinking water. After 1890 the Behera canal was finished, and the water supply of Alexandria is now taken from above the barrage and is in no further danger of becoming brackish.

The western or Behera canal had been made along with the barrage, but had been practically allowed to fall out of use, its place being taken by the two great pumping establishments I have already mentioned. The defect of this canal is that in its upper portion part of it is carried through soft sand, and even when this is not the case, the desert hills to its west have encroached on the valley, and sand drifts into it. The result has been a tendency in the canal to widen out its channel till it became a trench of 150 to 220 feet wide, with a bed from 9 to 12 feet higher than it should be. These defects have been slowly and patiently removed by Mr. Foster, till now the Behera canal is as good as any other. To narrow its bed, a series of groynes, composed of burnt lumps of clay (which it cost less to make than to carry stone a long distance), were placed for a distance of about 12 miles, 100 yards apart, starting from the two banks in pairs opposite each other, so as to keep the current straight in the centre, the result being a deposit of mud just where it is wanted on the sides. Further, to bind the sides, grasses, reeds and willows were planted along the edges. To keep the desert sand from blowing in from the west, mat screens were erected, which have proved very successful. It is found that when the sand piles up above a few feet against the screen it ceases to rise. Still further, both to stop the advance of the sand and to increase the cultivation, Mr. Foster has restored irrigation to a strip of land some two miles wide, to the west of this canal, and so the advance of the enemy is kept off.

In my first lecture I said that good irrigation must be accompanied by drainage, and this was a subject that had been absolutely neglected in Egypt. Soon after I arrived there I told Nubar Pasha that I thought it would be a much more difficult matter to get the water off the land than on to it. In Egypt, as in many other countries, there is a substratum of salt, and if the soil be saturated with water the spring level rises, and this salt is brought by degrees to the surface. If water continues to be poured over the land, and only dries off through evaporation or percolation, a salt efflorescence remains. The fields appear as though covered with hoar frost, and the result is barrenness. At the same time, the effect of the percolation is to saturate the subsoil, so that in local depressions the moisture comes to the surface, and the land becomes sour and water-logged. Of this state of affairs we had abundant instances in Egypt.

In *Plate* V. I have tried to represent a deltaic river with a system of canals laid out without any scientific method on the right bank, and laid out scientifically and combined with drainage on the left bank. You will remark that on the right bank there is no means for the water to escape from the fields and find its way into the sea. It must either evaporate or sink into the soil. This was the ordinary type of Egyptian canals. There were a few drains, but they too often discharged into canals, so that the brackish water from the upper fields was used to irrigate the lower fields; and in 1883 I found a well-founded belief that the land was yearly becoming less and less fertile. Of course, this is always apt to happen where the climate is favourable, water is abundant, manure is dear, and rents are high. There exists then a strong temptation to over-cropping, but the mischief increases with increased rapidity if not only the good qualities are taken out of the land, but bad qualities are added.

From the first, then, we had to turn our attention to drainage. Where it was possible we disconnected the tails of canals flowing into others. Where this would have interfered too much with vested interests we built large syphons or culverts, costing as much as £18,000 in one instance, under the canals, so as in every instance to allow the surplus water of irrigation to find its way off the land and out to the sea. These drains become larger and larger as they receive affluents, so that some are not less than 50 feet wide before they reach the sea.

I am sorry I cannot give you the total length of canals and drains in Egypt, but I am sure I am within the mark in saying that the canals are not less than 10,000, and the drains not less than 1,000 miles in length. There is not likely to be any great addition to the canals, but there is to the drains, which have been nearly all made since 1883.

The maintenance of all these canals, drains, and embankments involves yearly an enormous amount of digging—not less than from 33 to 26 millions of cubic yards have to be removed every year. Part of this was done by dredging when we went to Egypt, but vastly the greater portion by the corvée—a French word for which I know no English equivalent, but which in Egypt means unpaid, unfed, forced labour. The theory on which it was considered right to demand this labour from the Egyptian peasant has an appearance of sound logic in it. It was argued thus :—It is essential to the welfare of the agricultural classes (and omitting three or four cities the whole of Egypt may be said to be agricultural) that the canals should be kept in good working order, that the embankments should be maintained, the Nile floods controlled. These peasants have no money, but they have abundant leisure and good thews and sinews. It will do them no harm, and only serve to keep them out of mischief if they are called on to devote some of their leisure to doing all this necessary earthwork. In India in old days something of the sort was rigorously demanded ; but that the practice should not be abused and turned into simple serfdom it is necessary that the ruling classes should be upright, energetic men. Such a class of men have generally been conspicuous by their absence in lands ruled by the Turk.

So long as the irrigation throughout all Egypt was of the kind I have described as still existing in Upper Egypt, that is, merely employing the flood water, it is true that after their wheat was sown in November there was not much for the teeming population to do until harvest came in April. But when cotton and sugar cane began to be planted the operations of ploughing, sowing, weeding, manuring, etc., gave plenty to do, while the greatly extended network of deep canals much increased the labour of keeping them clear. This had been recognized long before we came to Egypt, and schemes had been discussed for relieving the corvée, but nothing was really done, and in 1883 I found an army of 85,000 men employed during 160 days every year, dragged for many miles from their villages, supplying their own tools, unpaid, unfed, unlodged. The same man would not work through all these months, but it was the duty of the village sheikh to see that his village furnished its full quota, and a second corvée of wretched wives and children were constantly coming and going, taking food to the workmen. This would have been bad enough had the burden been divided fairly among all; but it was most unequal. The lands of the delta are divided about equally between the large properties of wealthy pashas, beys, and a few Europeans, and the small properties of the peasantry, three or four acres each. Of course, the large proprietors have a swarm of tenants and dependents, and in justice they and their dependents should have borne their share of the common burden; but this they had long ceased to do. On the contrary, through their influence with corrupt officials, they not unfrequently were allowed to employ the public corvée in doing their private work, so that the whole earthwork of the country was practically done by the serf labour of the poor unprotected class. The rich pasha employed his dependents in weeding and cleaning his 500 acres of fine cotton. He did not concern himself with clearing the canals that watered his land. That was done for him by his poor neighbour, whose three or four acres yielded only half return, because instead of weeding them he was away clearing the rich man's canal.

You may suppose we Britons were not going to let this iniquity go on without a protest. What first struck me in 1883 was not so much the oppression of the corvée, which I had not then fully grasped, as the extremely clumsy machine which this corvée was for doing good earthwork. The native engineers were, with a few exceptions, ignorant, lazy, and dishonest. In December and January they were required to make out their estimates of earthwork required. In each province was a council of village sheikhs. The engineer presented his estimate and made a requisition for the labour required. The sheikhs settled where the men were to come from, government approved of it, and it was the duty of the civil governor to see that the men went to the work. The engineer's estimates were of the wildest. All should have depended on carefully levelled sections of the works. There were not six good levels in Egypt, nor 12 engineers in whose levelling I trusted. As you may suppose, the men did not work with much heart. The engineers took no trouble about measuring it up. Much of it consisted of clearing out canals which could only be kept dry for a limited time, say three weeks. Before the work was done, the irrigators demanded that the canal should be re-opened. Pressure was put on the engineer. Once the water was admitted no one could prove that they had not finished their work, and that the clearance had not been complete. So work was scamped. The irrigation failed at the time of need. No one was satisfied save the rascal whose pockets were full of bribes received from the unfortunate fellaheen to get off their burden. He who could not bribe had to work the harder, and perhaps be bastinadoed before it was done. And so the burden of Egypt rolled up heavier and heavier, truly a land full of lamentation and woe !

I must give the more cultivated Egyptians credit for this, that they recognized the mischief of the corvée, but what was to be done to stop it ? The revenue was barely enough to meet the wants of the country. It was out of the question laying on heavier taxation. The ordinary, dull-headed, uneducated village sheikh was perfectly contented that the corvée should continue. He never sent his son to it, and it gave him a convenient way of paying out old scores by sending off his enemies in the village.

Our first measure was to get sanction to allow the corvée to redeem themselves if they liked by a payment of six shillings a head. We did not think this just, for it was a tax that should have evidently been levied on the land, not on individuals. But still it was an improvement. We found the fellah ready to pay in as redemption money £116,535 in 1885. With this sum our next step was to enter into contracts with three dredging companies, which enabled us to have much of the earthwork done in the most satisfactory way by machinery. For the rest we invited tenders for contractors in the usual way. This met with a storm of opposition. We were assured that the peasant would not work unless forced to do so. Contractors were looked on with the deepest distrust. Every little failure was dwelt on with satisfaction. Even the late Khedive, our kind-hearted friendly supporter in every difficulty—even he was afraid of this new-fangled notion of contractors. Then Nubar Pasha, at that time president of the council of ministers, came to our help. He asked me for what sum we could pay for all the earthwork, so as entirely to dispense with the corvée. I told him we should require £400,000 a year. Then in the face of all sorts of financial difficulties he managed to find us £250,000. This, of course, greatly lightened the burden, and Riaz Pasha, who succeeded him in 1888, found the remaining £150,000. Since the 1st January, 1890, the canals, drains, and embankments have been maintained by free paid labour, precisely as such works are in England. I do not believe since the

Jews furnished Pharaoh with a corvée to make bricks has there ever been such a thing as this known in Egypt. There is nothing during my stay in the country that it gives me greater pleasure to have been connected with than this abolition of the corvée, and there is nothing, I believe, that has gone so far to make our rule popular, for it appeals to the whole people, and there is no fellah so stupid as not to see the difference between being driven off by force to work without pay, and being asked to do the same work if he likes and being paid for doing it.

There is one form of corvée that still exists, and which we have not thought it prudent to meddle with. During the Nile flood it has been the custom always for the peasantry to turn out and watch the river banks by day and night. They build grass shelters about 80 yards apart. At night they have lanterns. At places of known danger they have parties held in readiness in case of accidents. All this employs several thousand men. But it is work they are used to. I question if it would be possible just now to obtain a contractor in whom we could rely; and as we have not yet taken to employing contractors to fight our battles for us, I do not think we need readily expect the Egyptian to fight their great annual battle with the Nile by means of contract.

In ordinary years the Nile can be controlled by employing the measures which centuries have taught them to be the best; but about once every five years the floods rise with exceptional power. Such a flood we had in 1887, and again this year there has been a still greater one. No flood of such height before 1887 had ever occurred without breaking the embankments and causing widespread disaster. I am glad to say that both in 1887 and this year the waters were conveyed safely to the sea; but they were times of very great strain to all concerned. Every steam launch available was put into requisition, and the irrigation officers kept constantly patrolling their beats. The subordinate engineers were supplied with sailing boats. Mr. Willcocks' orders were that each native chief engineer should carry on his boat 500 sacks, each assistant 250 sacks. Each had besides 20 spades, 50 baskets, 200 stakes, balls of twine and packing needles to sew up the sacks when filled with earth. Each boat had two lanterns and a drum, so that if the inspecting officer were passing in his steamer, and the subordinate were in difficulties, he could always by day or night attract attention and make his presence known. From 15 to 20 boats full of stones were always kept floating down the river. These are most useful for forming groynes, protecting the flanks of masonry works, and diverting a heavy current; but in an ordinary earthern embankment to try to mend a weak point with stone is often bad, for it is impossible to make a water-tight joint between stone and earth. Sand-bags are very superior for this purpose. For protecting a crumbling bank a row of stakes should be driven first in deep water, and behind these a wall of sand-bags built nearly vertically. Or the space behind the stakes may be packed with brushwood, cotton stalks, or the long stalks of the millet, called *durra*. Sometimes it is of no use to fight the first line of defence. Then a second embankment is run up behind it. By expedients such as these the river is kept within its banks; but it is a long, anxious struggle, where the engineer is liable to have to turn out by night or by day, and steam is always up in his boat. The struggle lasts for some six weeks, and all are tolerably exhausted before it is ended.

After our high flood experiences of 1887 we had a very unusually low flood in 1888, with one exception the lowest of the century, and the loss of revenue that year was more serious than all the damage done by the flood.

I have explained how in Upper Egypt the whole Nile Valley is divided into great flats, which are put under water and saturated. In 1888 there was an area of 260,000 acres over which the water never flowed. This caused a loss of land revenue of about £300,000, and, as you may suppose, the loss of a whole season's crop to the farmer must have been far greater. The mischief was much checked by the timely measures directed by Colonel Ross (I was absent myself in England). The following year our attention was naturally directed to the subject, and from statistics we found that even in ordinary years there was an apparently preventible loss of £38,000. Col. Ross threw his whole soul into this question, and the result has been the construction of so many canals, syphons, regulating sluices, and escape sluices in Upper Egypt that I believe, however defective future Nile floods may be, it will be always possible to get the water on to the land.

When the surface water of the river is higher than the fields right and left there is nothing easier than to breach the embankments and flood the fields. In fact, it may be more difficult to prevent their being flooded than to flood them; but in such years as 1888 the river nowhere overflowed the valley. To inundate it, therefore, it is necessary to construct canals having bed slopes less than that of the river, along which the water flows until its surface is higher than that of the fields. Supposing, for instance, the slope of the river to be four inches per mile, and that of the canal two inches, it is evident that at the end of a mile the water in the latter will be two inches higher than in the former; and if the surface of the land is three feet higher than that of the river, the canal gaining on it at the rate of two inches per mile will reach the surface in 18 miles, and from thence onwards be able to irrigate. But to irrigate this upper 18 miles water must either be raised artificially, or supplied from another canal taking its source 18 miles further up. This is quite practicable, but it would involve the country in enormous lengths of canal between the river and the field. Fortunately, circumstances are not so unfavourable. Throughout Egypt I have explained to you that, following the deltaic principle, the fields on the river's edge are higher than those further back. A flood, then, three feet below the surface of the bank is often not more than one foot lower than the average surface of the valley; so that the canal gaining two inches per mile will reach that surface in six miles. The slope of the river, moreover, is taken on its winding course, and if it is four inches per mile the slope of the axis of the valley parallel to which the canals may be made to flow is at least six inches per mile; so that a canal with a slope of two inches gains four inches every mile. This principle was well understood by the old Egyptians, but in the practical application of it there was hopeless failure, until Col. Ross produced order out of disorder.

The system of having one canal overlapping another has one difficulty to contend with, that occasionally the desert cliffs and slopes bordering the valley come right down to the river, and it is difficult if not impossible to carry the higher level canals past these obstructions. I have shown you already how the great basins are flooded, and only one crop a year is produced from them; but I should add that on the higher zone bounding the river right and left, it is the custom to get more duty out of the land than in the great basins beyond.

Advantage is taken of the nearness of the river to raise water by water-wheels or *Shadoofs* from the Low Nile, and thereby to grow crops of sugar cane, maize or vegetables. When the river rises, these crops, which often form a very important part of the years' produce, are still in the ground, and these fields require water in moderate and regulated quantities like the land of Lower Egypt. This cultivation is locally known as *Nabári*.

Plate VI., for which I am indebted to Colonel Ross, shows for each bank of the river a typical system of basins with its canals, embankments and masonry works. The basins are marked A, B, C, etc., each surrounded with its embankment. The area of each is given in acres in figures.

It will be seen, beginning on the east or right bank, that a high level canal from an upper system is carried past a steep slope, where, perhaps, it is cut entirely out of rock, and divides into two at the head of the system. The right branch waters all the desert slopes within its reach and level. The left bank, passing by a syphon aqueduct under the main canal of the system, irrigates the high lands bordering on the river. All this high land irrigation is what I have termed *Nabári*, and in years of very good flood this high level canal would not be wanted at all, as the irrigation could be done from the main canal, and it would have this great advantage, that the water taken from it would carry with it much more fertilizing matter than could be got from the tail of the high level canal which left the river, perhaps 25 miles up. On the other hand, in years of defective flood, these lands would be absolutely dry and barren but for this canal. The main canal flows freely over C and D, and if the flood is good, over B and part of A. It is carried round the next desert point, and to the north becomes the high level canal. The masonry works required for this system are a syphon to pass the high level canal under the main canal near its head, bridges fitted with regulating apparatus where each canal passes an embankment, and an escape weir at the tail of the system just south of the desert point to return surplus water to the river.

When the floods are favourable, cuts may be made in river embankments and small shallow canals of muddy water drawn in. But care must be taken not to get too much to drown the *Nabári*, and when the flood is deficient every effort must be made to keep the precious water from bursting back into the river too soon. Turning to the left bank, there is the same high level canal from the upper system irrigating the basins K, P and L, as well as the large basin E in years in which it cannot be irrigated directly from the main canal. Here you will observe there are two main canals, one following the river and irrigating a series of smaller basins, and throwing out a branch to its left. This canal, fed by the surplus water of the basins, will form the high level canal of the next system. The other main canal passes under the desert slopes, and is the main channel of supply for all the basins F, G, H, R. For this system two syphons will be required near the head, regulating bridges for the two main canals, similar bridges under the embankments, and a surplus escape weir back into the river. Many of these canals have existed since long before our time, and there were a certain number of masonry works. Colonel Ross' project was for 99 new masonry works, costing £228,000 ; 385 miles of new canal, and 297 miles of widening and deepening canals, costing £567,609 ; total, £795,639. In execution he considerably modified his first project and reduced his estimates, but the principle is such as I have stated, the money was provided, and I am glad to say the works are nearly completed.

The outlay has been very much increased owing to the fact that some 20 years ago the railway from Cairo south to Assiout was carried parallel to the left bank of the river for a distance of 269 miles, and a very important perennial canal, known as the Ibrahimieh, on the same principle as those I have described in Lower Egypt, but with no dam at its head like the barrage, was taken out of the river at Assiout and carried for 200 miles along the west side of the railway, the object of which was to give irrigation to extensive sugar cane plantations, the property of the Khedive Ismail. This railway and canal was supplied with very few bridges or syphons to allow of the passage of the muddy Nile water into a most important system of basins to the west. They could only be supplied by surplus water from basins further south, which had been deprived of all its fertilizing mud, and the result was a yearly decrease of productiveness to an alarming extent. These evils are now all being remedied. The Ibrahimieh canal has been especially for eight and a-half years the charge of our brother officer Major Brown, who has carried out many important improvements on it, and has built several large culverts beneath it take this river water to the distant basins. The largest and most important of his works, an escape dam consisting of 60 openings, formed the subject of an interesting paper by him lately published among the *Occasional Papers* of our Corps, so I need not allude further to it here.

I find, while this my lecture is attaining a formidable length, that there are many most interesting and some very important works recently executed in connection with the irrigation of Egypt which I have no time to touch upon. I shall conclude by telling you something of a very great project, which, although it has got no further than surveys, plans and calculations at present, will, I trust, be put into execution ere many years are past.

Herodotus has related that in his time, in a province of Egypt now called the Fayum, there existed an immense lake Mœris, which was filled each Nile flood, and which was used as a source of irrigation during the rest of the year. It has been, and is still, a great question where this wonderful lake was situated, and the very last word on the subject is to be found in a pamphlet written by Major Brown and illustrated by most admirable photographs taken by him. This was published only last month by Stanford. An ingenious American gentleman, Mr. Cope Whitehouse, has devoted much attention and written much on the subject lately. He thinks he has discovered where Lake Mœris really was. He does not agree with Major Brown's views, and although I think the evidence is against Mr. Whitehouse's archæological views, still there is no question that he has discovered a curious saucer-like depression in the western desert, some 60 miles south of Cairo, and 12 miles off the river, and he has urged with great insistance that this depression should be used for the storage of Nile water. A rival scheme, with the same object, was advanced some years ago by a French company who proposed to place a dam across the river at a place Silsileh, about 560 miles south of Cairo, where the river forces its way through a chain of low hills, and pointed out that a succession of such dams might be built further south. For some time after we began work in Egypt, we had too much to do economically employing the water at our disposal to go into projects for increasing the supply, especially as there seemed no chance of there being money to carry such projects out. But lately we have arrived at the end of our water supply. When the Nile is at its lowest we use up all that is available, and if the cultivation of cotton or sugar-cane is to increase, more water must be found. Mr. Willcocks has, therefore, been employed in carefully surveying possible reservoir sites, measuring the discharge of the river at all periods, and estimating and designing dams and sluices. If water can be stored when the Nile is at its highest, some control may be exercised in years of unusual flood, and if we could double the Nile supply when water is at its lowest we might count on a large increase of the most valuable crops.

Mr. Willcocks has very carefully examined Mr. Whitehouse's proposal for converting into a great lake the depression which he discovered, and which is called the Wadi Raian. He considers the project feasible, but that it would be more costly than others; but the matter has not yet been finally decided.

Mr. Willcocks pronounces against the Silsileh project owing to the great depth of the river there, and to the unsatisfactory nature of the sandstone rock. He has, however, found sites at the first cataract at Assouan, at the second cataract at Wadi Halfa, and at an intermediate point, Kalabshah, where abundance of the best granite is to be had, and where it seems quite possible to erect such a dam. Wherever it is built it must be a stupendous work. Mr. Willcocks has been asked to find the means of increasing the Nile supply for 100 consecutive days a year by a volume of 8,000 cubic feet per second. The dam would be about 72 feet high. The lake thus formed when full would be about 200 miles long. One very grave difficulty I foresaw at first. In my first lecture I told you a tank has an age like a human being. It ultimately becomes filled up with silt and ceases to exist. Now the Nile flood is charged with alluvium to a very great extent, and I could not see, and do not see now, how, if we ponded up the water in August and September, when it is muddiest, we could prevent our great reservoir from being filled with deposit in a few years. But Mr. Willcocks has pointed out that the reservoir sluices might be left open, so as to pass the whole flood unchecked until November or December, a time when the water is comparatively free of deposit, and if the sluices were closed then we might pond up enough to give us the volume required by March. This is a most important point, for although it will prevent the reservoir being used to regulate excessive floods, it will ensure it against being filled up in a few years.

With this additional volume of water at the disposal of Government it is probable that the system of perennial irrigation practised in the delta would be extended to all the lands north of Assiout, and if so a dam would be built across the river at this point. The whole outlay to carry out this programme, to form the reservoir, to make the canals for distributing the water, and to make a new weir or dam at Assiout, would be probably 2½ millions sterling, a sum which it would have been absurd to dream of in Égypt only a few years ago, but which may be perfectly reasonable if the country pursues its present splendid path of progress.

My lectures are now finished. I must end as I began by expressing my conviction that if you have found them uninteresting the fault lies with the lecturer, not with the subject. Anyhow, they will serve to show you that some good work on rather a big scale has been going on in Egypt in the last few years. Royal Engineers and civil engineers have equally been employed on it, and if any credit has been gained it may be equally divided between them.

PLATE I.

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n Map of Lower Egypt