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PAPER I.

PROGRESS IN THE PRACTICE OF SURVEYING.

BY MAJOR A. C. MACDONNELL, R.E.

To deal fully and adequately with the progress of a subject which began to develop over 4,000 years ago is a task I do not pretend to undertake. I hope, however, by touching briefly on a few of the more important and interesting points in the evolution of the practice of survey, I may promote a desire on your part to commence a closer and more intimate study of a subject, a practical knowledge of which is indispensable to all Royal Engineer officers.

I always think, and I hope you will agree with me, that the contemplation of the earlier struggles in the growth of any field of enquiry enables one to more fully appreciate and to take a more intelligent interest in the subject itself as it now stands in its present state of development.

In spite of a desire on my part to limit my remarks to the map-making branch of survey, I have been obliged to deal very generally with the developments of astronomy, as the earlier methods of surveying cannot possibly be emancipated from it. I have, however, endeavoured to confine any necessary excursions into this profound and scientific subject, as far as possible, to simple generalizations.

As each man stands in the centre of his horizon, the portion of the earth seen by him has the appearance of a circular disc.

The whole world was thus in ancient times conceived as a circular disc surrounded by sea.

We find, therefore, from the earliest times maps depicting the world to be a circular plane. Geographical knowledge in those days increased towards the East, and also to the West, and but little to the North and South; and gradually gave rise to maps of elliptical plane shapes. We can go back as far as the time of Rameses II., an Egyptian king, 1400 B.C., and find maps and routes constructed on this principle. The most ancient map known to us is that of a gold-mining district in Nubia. Its date is 1600 B.C., and is now in the Turin Museum. The perspective in it is amusing, as in order to show that a road passes between two hills, one of the hills is drawn upside down. These maps were, of course, drawn entirely by eye and proportionate distances to scale.

In order to define our ideas it will be as well to tabulate the successive periods or schools during which the progress of early astronomy may be said to be divided.

The Chaldeans (*i.e.*, Babylonian Priests)	from 3000 to 1500 B.C.
The Egyptians	1000 to 400 ,,
The Greeks (or Alexandrian School)—	
Eratosthenes	3rd Century ,,
Hipparchus	2nd ,, ,,
Ptolemy	2nd ,, A.D.
The Arabian School (at Bagdad) ...	2nd to 14th Century A.D.
Modern Schools	15th Century onwards.

The Chaldeans (about 1500 B.C.) first divided the entire circle of the ecliptic into twelve signs of the zodiac, and afterwards into 360° 60′, etc., together with corresponding divisions of the hour, etc., and also conceived the sexagesimal system of numeration.

Their amount of astronomical knowledge is difficult to arrive at. Earliest written annals of the Greeks, Etruscans, and Romans are irretrievably lost. The traditions of the Druids perished with them. A Chinese Emperor has the credit of burning "the books" extant in his day (220 B.C.), and of burying alive the scholars who were acquainted with them; and a Spanish adventurer destroyed the picture records which were found in the "pueblo" of Montezuma.

The Chaldeans certainly observed and knew of certain phenomena such as the seasons, and also, in common with the Egyptians, made charts of the stars and divided them into constellations.

It is not, however, till we arrive at the Greek school we find any *records* of marked progress, or, indeed, commencement in a knowledge of the fundamental principles of astronomy.

Both the Chaldean and Egyptian Schools had observed that the sun moved among the stars, and returned to the same place after a cycle (one year), and they gave names to the constellations passed over as the twelve signs of the zodiac. This constituted the circle of signs.

Anaximander (early Greek) showed that this circle is obliquely situated with regard to the circles in which the stars move about the poles.

Soon after this the doctrine of the sphere was enunciated, correctly describing the heavens as a celestial sphere turning round the axis of the earth, and defining correctly the equator and the tropics. We see, therefore, at the commencement of the Greek School a few important fundamental principles were fully recognized, and they were rapidly followed up by advances in geometry and trigonometry, both plane and spherical. Euclid's works at this time were some of the most important.

As regards the division of time, the periods of the day and night must, of course, have been apparent even to Adam and Eve.

The Egyptians, however, lay claim to the discovery of the yearly period (365 days).

To ascertain the number of days in a year it was necessary to count the recurrences of certain phenomena, such as the rising of the sun over exactly the same place in the horizon, the greatest altitude to which the sun reaches, and the proportion of length between day and night.

The number of days counted between such phenomena would determine the number of days in a year, and if recorded for several cycles greater precision could be obtained; but as the Hottentots were unable to count or enumerate figures beyond the number of the fingers on their hands and feet, it is evident that though they observed the phenomena, they could not discover the number of days in the year.

The Greeks, however, recorded careful observations, and they found that 365 days carried on for a number of years threw out their calendar after some time, and that the sun phenomena did not recur annually exactly on the same date.

This was due to the fact that the real year is about 365¼ days. All calendars must, therefore, be corrected occasionally for the extra quarter of a day.

Different nations adopted different methods for bringing this error right, and Julius Cæsar, in the 1st century B.C., by the advice of Sosigenes, adopted the method of adding one day every four years, which system we still retain; and in order to correct the derangement which had already been produced he added 90 days to a particular year of the usual length, which then became known, and very naturally, as the "Year of Confusion." Pope Gregory XIII., in the 16th century A.D., made some slight modification in the system, which was termed the Gregorian Calendar, and was adopted by all Christian nations except Russia.

The grouping of stars into constellations and the giving of them fancy names appears to be also of very ancient date, and the similarity in different countries is very remarkable. The Chaldean, Egyptian, and Grecian skies have a resemblance which cannot be overlooked.

Job ix., verse 9, refers to the stars "Arcturus," "Orion," and "Pleiades."

Aristotle (4th century B.C.) may be looked on as the first to philosophize on the globular form of the earth. Pliny, the Greek naturalist, defended the theory by several ingenuous arguments, such as that the end of the ocean would fall if it were not rounded off, etc.

Amongst the learned Greeks it came to be accepted in time that the earth *was* a globe, and that the motions of the heavens were the results of motions in a revolving sphere. It was on this principle that Ptolemy elaborated and described his Ptolemaic system, which was roughly that the earth was *fixed* in space, and that the sun, moon, and stars, etc., revolved round the earth's axis in circles or orbits of their own. This theory maintained its position for 1,400 years.

On further examination of the planets, etc., there was some apparent eccentricity which, however, followed a certain regularity, and the planets appeared nearer to the earth at certain periods than at others.

"Hipparchus," therefore, to account for these eccentricities, applied the principles of epicycles and eccentrics instead of mere circles to the motions of the planets.

Plate I. and *Fig.* 1 illustrate the supposed motion of the planets in this way.

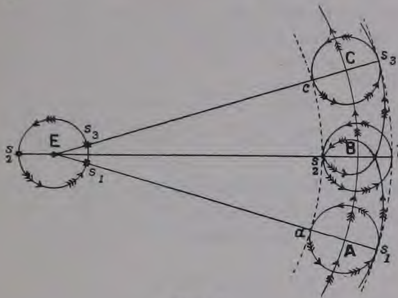


FIG. 1.

Hipparchus was a wonderful astronomer, and his fame as such can never die out. His theories and researches enabled him to embody all the most exact knowledge then extant, and to make clear and tabulate the exact relative places in the heavens of the sun, moon, and stars, and the connection between space and time.

Trigonometry was created by Hipparchus for the use of astronomers, and spherical trigonometry, being directly applicable to astronomy, was actually developed before plane trigonometry.

He also expressed the value of an angle by the relation of the chord to the radius, and afterwards established a table of chords for different angles.

He also suggested zones of latitude and longitude, and Marinus, of Tyre (150 B.C.), was the first to actually map the world on these principles.

Ptolemy afterwards arranged all this preliminary work, and presented it in a scientific form, writing a most complete work, now known as *The Algamest*, which was but little improved or added to for 1,400 years.

Ptolemy can, therefore, be considered scarcely second in fame to Hipparchus. He assumed the earth was a globe, and covered with a network of *parallels* and *meridians*, terms which he was the first to employ.

The following maps will give a good idea of the progress of mapping, each being fair specimens of their respective centuries :—

Hecatoeus' Map of the World ...	500 B.C. (*Plate* II.).
Eratosthenes' Map of the World...	250 B.C. (*Plate* III.).
Ptolemy's ,, ,, ,, ...	150 A.D. (*Plate* IV.).
Mappe Mundi	8th Century (*Plate* V.).
Hereford Map of the World ...	13th Century (*Plate* VI.).
Toscanelli's ,, ,, ,, ...	14th Century (*Plate* VII.).
Schöner's ,, ,, ,, ...	1523 A.D. (*Plate* VIII.).

Toscanelli's map is interesting, as it was the only map which Columbus used when he started on his first voyage in 1492, and which led to his discovering the great American continent.

Instruments.

It is now necessary to consider the instruments employed in those days.

A meridian line was apparently found easily from the earliest ages (Chaldean) by the shadows of an upright pole cutting the circumference of a horizontal circle laid out on a floor, a system even now employed by ourselves, and described in our present text-book of military topography.

The Polar star was also used to ascertain the azimuth or direction of the meridian.

Altitudes were the first angular measurements attempted to heavenly bodies.

They were first expressed by comparing the length of the shadow of an upright staff with the length of the staff itself, and, in fact, is our present expression for the tangent of the angle.

The most ancient record of such a measurement is by "Gautil," who states that "Tchon Kong" in 1100 B.C. found the length of the shadow of the staff at "Honanfou" at the summer solstice to be 1½ feet, the staff being 8 feet.

An instrument on this principle was called a Cross Staff (see *Fig.* 2).

It consisted of a graduated pole with cross pieces (also graduated) fitted to work on it. It was placed approximately in the meridian by compass, and the rod directed on the horizon. The cross, being vertical, was worked up to the sun till the latter reached its greatest altitude at noon; the readings were then taken, and the proportionate lengths of upright and horizontal gave the altitude.

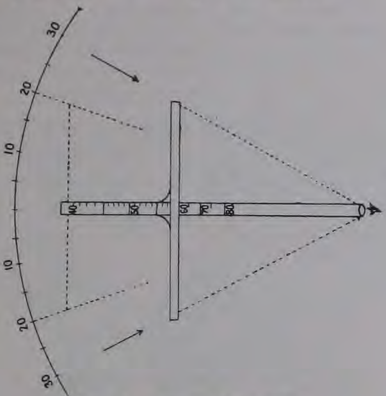


FIG. 2.—*Ancient Cross Staff.*

I must here refer briefly to even an earlier form of measuring instrument in the shape of the Great Pyramid of Ghizeh, which we have strong evidence to show was used as an astronomical observatory. It was built by the Egyptian King Cheops about 3000 B.C.

Its position is most accurately placed in the meridian.

One of the galleries points with very great precision to the Pole star of the period (*i.e.*, "α," Draconis).

These galleries were probably used for observing accurately the transits of the heavenly bodies across the meridian.

Plate IX. shows the platform as it was possibly used for observing purposes until "Cheops" died, when it was built up and formed his tomb.

After the cross staff the next advance in angular measuring instruments was the observations made with a divided circle.

The most ancient known instrument based on this principle was the hemisphere of "*Berosus*," 4th century B.C. A hollow hemisphere was placed with its rim horizontal, and a "style" was erected in such a manner that its extremity was exactly at the centre of the sphere. The shadow of this extremity, cast by the sun on the concave surface, had the same position with reference to the lowest point of the sphere which the sun had with regard to the highest point of the heavens.

The Greeks may, therefore, be said to have established the use of circular measuring instruments; and the first instruments of this kind were called "armils." One was permanently fixed in the portico of Alexandria, and long used for observations.

FIG. 3.—*Ancient Armil.*

Fig. 3 will give an idea of the instrument, except that the first instruments called "armils" were constructed with an inner ring sliding round, and with two pegs on it at opposite extremities of a diameter, standing at right angles to the plane of the circle; the pegs were directed on the heavenly body when its altitude was required. Such an instrument, with a pointer and sights, was better known afterwards as an "astrolabe," though some of the later astrolabes were considerably added to and improved.

The outer circles were divided into degrees, and the degrees again into 10′ intervals in Ptolemy's time.

Ptolemy improved on the "armil" by the use of the quadrant, which was merely a wooden or stone quadrant of a circle divided into degrees, etc. (see *Fig.* 4).

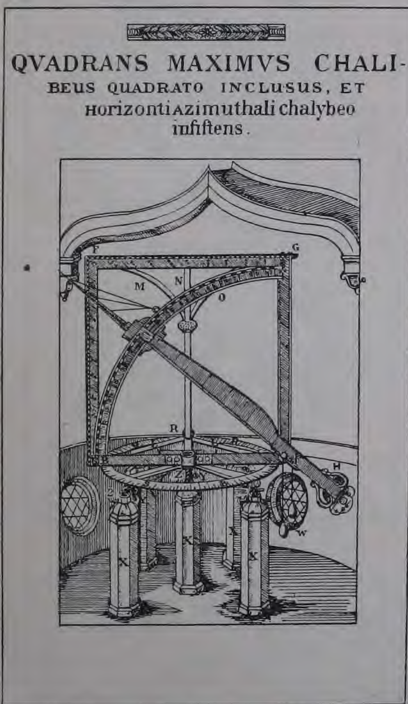


FIG. 4.

The quadrant depicted in the figure is a facsimile of a very much later type used in the 16th century, but illustrates the principle of it.

Ptolemy still further improved on the quadrant by elaborating the armil into an astrolabe (see *Fig.* 5).

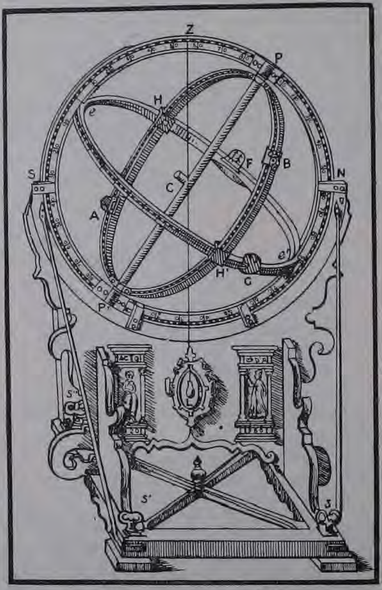


FIG. 5.—*The Astrolabe.*

This, you will perceive, can be placed in the meridian, and has other circles which can be placed in the equator and ecliptic. Circular measurements can then be made of altitudes, declinations, or of right ascensions.

MAP MAKING.

I must now revert to the subject of maps, and the way in which they were constructed.

The first application of astronomy to geographical mapping was made by the famous arctic navigator "Pytheus," of Marseilles, 326 B.C., who determined the latitude of Marseilles astronomically.

It is presumed he used an armil of some kind, and observed the meridional altitude of the sun at noon about the time of the equinox, or, perhaps, the altitude of the Pole star. I find no record as to which, but he appears to have been the first to determine a latitude astronomically.

In Ptolemy's time latitudes were determined in this manner astronomically by the astrolabe, and longitudes were ascertained approximately from reputed distances, the degrees being computed from an imaginary size of the earth.

Ptolemy having constructed his network of parallels and meridians, and depicted them on a sheet of paper by a "projection," plotted each place by its latitude and longitude.

Ptolemy's assumption of the size of the earth was, unfortunately, so far wrong that his degree of latitude was actually about $\frac{1}{6}$ smaller than it ought to have been.

He also took "Marinus," primary meridian of longitude, to be at the "Canaries," the most western land then known, and the position or distance of which from Alexandria was most uncertain; this caused his longitudes to be distinctly erratic (see *Plate* X.).

Ireland too far N., and Scotland lying E. and W.

His description of the Nile is interesting, as he states that it derived its waters from the confluence of two rivers, one of which took its rise in two lakes a little to the south of the equator, and that the other also had its source in a lake, both facts, which were only substantiated 1,600 years afterwards.

His methods of projection differ little from those of the present day.

He used what is known as the stereographic method; and here I will venture to interpolate a few remarks on the different forms of projections.

Projections.

If you take any sphere which has a skin, such as an orange with its peel, and try to flatten the skin out on a plane surface, it will be found that it cannot be done without tearing or folding over some of it, and we are thus confronted with an impossible problem! How are we, therefore, to represent the surface of the earth on a flat map? We are forced to adopt expedients which, though approximate, are practically made to serve our purpose.

Projections of the spherical on a plane surface may be classified under two general headings :—

(*a*). Perspective.
(*b*). Developing.

A perspective projection is the representation of the earth as it would appear to an eye placed in a certain position with regard to its surface.

The representation will vary according to the position of the eye (or point of projection) and to the plane of projection (or surface on which the representation has to be made).

Perspective projections are chiefly used for maps of the world, and are not of much use, therefore, to the ordinary field surveyor.

A developing projection makes use of the fact that the curved surface of a cone is capable of being spread out or represented upon a plane without any alteration in the figure or dimensions of its parts. That is to say, the skin or surface of a cone can without difficulty be unrolled from off the cone and spread out on a plane surface.

To this class belong all conical projections, and are used in the representation of smaller portions of the globe than the perspective projections, and therefore more used by the field surveyor.

The perspective projections may be sub-divided as follows :—

Orthographic.
Stereographic.
Globular.
Gnomonic.
Sir H. James.

Now imagine the globe covered with a network of parallels and meridians and transparent, and let AB be the plane of projection (see *Fig.* 6).

In the orthographic the eye is at an infinite distance, and the points on the surface *bcd* will be projected on AB at *b'c'd'*.

In the stereographic projection the point of sight is at C, and the points are projected on AB as shown. It will be noticed that the lengths on AB decrease outwards in the orthographic and increase in the stereographic.

In the globular projection the point of sight is outside the sphere, and at a distance from it equal to the sine of 45° of one of its great circles (see *Fig.* 7).

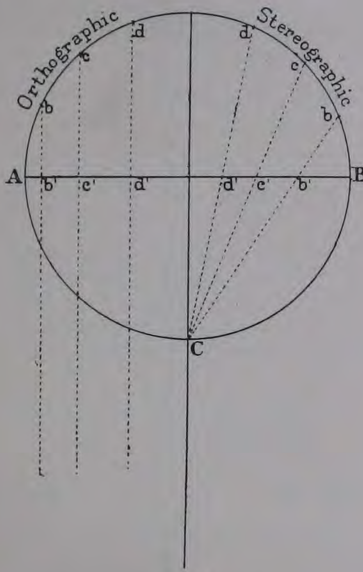


FIG. 6.

The orthographic projection distorts too much, and is not therefore adopted (see *Fig.* 8).

The stereographic is superior to both the orthographic and globular, but owing to the greater ease with which the latter can be constructed it is more generally adopted by unscientific atlas makers.

The gnomonic has the point of sight at the centre of the sphere, and imagines the sphere itself to be enclosed within a circumscribing cube, upon the six equal faces of which the projection is made.

This projection is only used for star charts of the heavens, as it has one great advantage—that all stars which appear on the same line in the heavens are found on the same line on the map.

In Sir H. James' projection the plane of projection is not the usual one of a great circle, but is made to coincide with a circle removed 23° 30' from the assumed great circle and towards the point of projection, which latter is at a distance from it equal to half the radius (see *Fig.* 7).

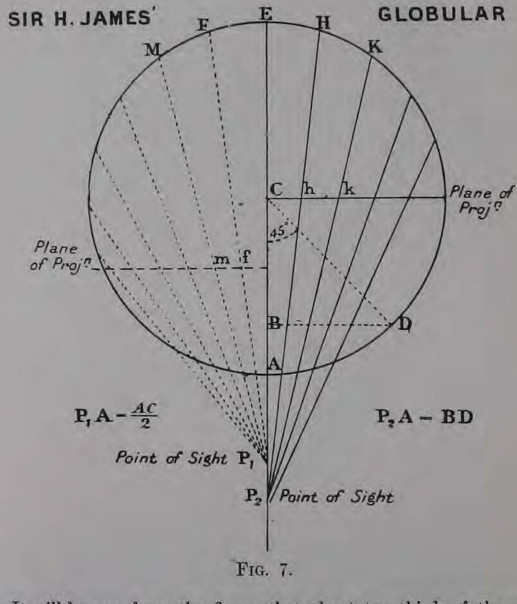


FIG. 7.

It will be seen from the figure that about two-thirds of the surface of the sphere can be projected in this way, whereas only half was projected in the others.

Developing Projections.

Fig. 9 shows a simple conical projection. ABCD is a portion of the earth's surface to be represented on a plane surface.

Let EF be the middle latitude of this portion, then the cone touching the earth at this latitude may be assumed for practical purposes to coincide with the portion of the sphere ABCD.

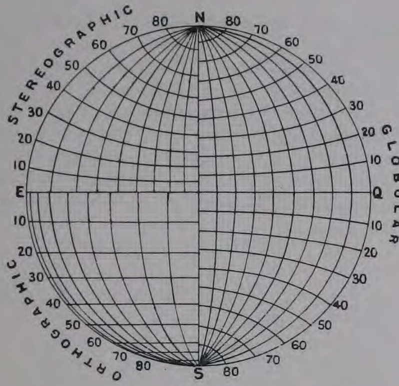


FIG. 8.

CONICAL PROJECTION.

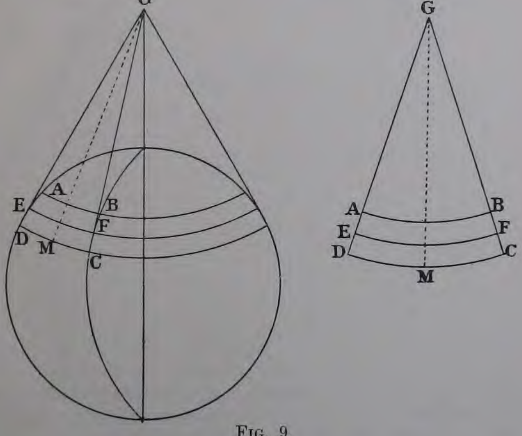


FIG. 9.

This conical portion is then unrolled and laid out flat, as shown in diagram.

It is evident that the length GE can easily be calculated, and with the known length of a degree of longitude we can easily construct this conical surface to any given scale on a sheet of flat paper.

An excellent modification of the simple conical projection consists in regarding the cone not as a tangent to the sphere, but as inscribed partly within it, and as entering it at two points between the middle and extreme parallels of the zone to be represented (see *Fig.* 10).

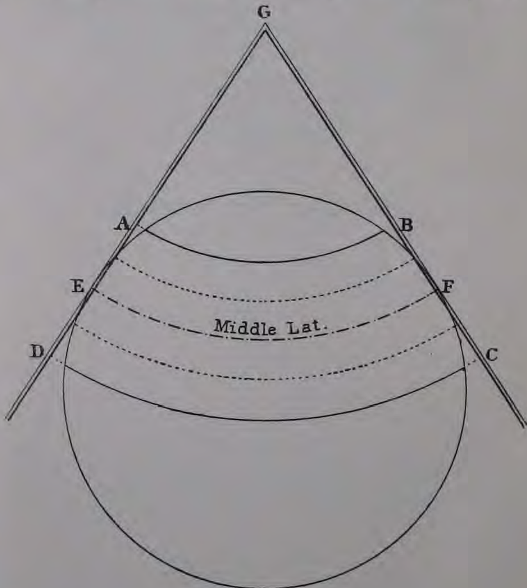


FIG. 10.

The best design of this description is due to De Lisle (a Russian), who made his cone intersect the sphere in the two parallels exactly half-way between the middle and extreme parallels.

I now come to two important modifications of the simple conical, as they are those which would appear to recommend themselves as being more scientific and practical for mapping very large areas, such as India and Burmah or the American continent.

These are the polyconic and the rectilinear tangential.

In the polyconic the parallels are no longer concentric arcs, but each is drawn with a radius equal to the side of the cone, which is tangent to the sphere at each parallel in turn. The sides of these cones therefore shorten as the pole is approached, and each parallel has, therefore, a different centre, and they diverge from each other towards the sides of the map (see *Fig.* 11).

The parallels are obtained as follows :—

A central meridian is drawn down the centre of your paper. The points at which the parallels cut the central meridian are marked off to scale by reference to any table giving in miles the lengths of the degrees of latitude between the different parallels. Each parallel is then drawn as part of a circle with the centre on the central meridian produced if necessary, the radius being the distance from the latitude in question to the apex of a cone touching the earth all round at that parallel of latitude.

The meridians are obtained by setting off the intervals of longitude to scale along each parallel.

This polyconic projection is used by the United States.

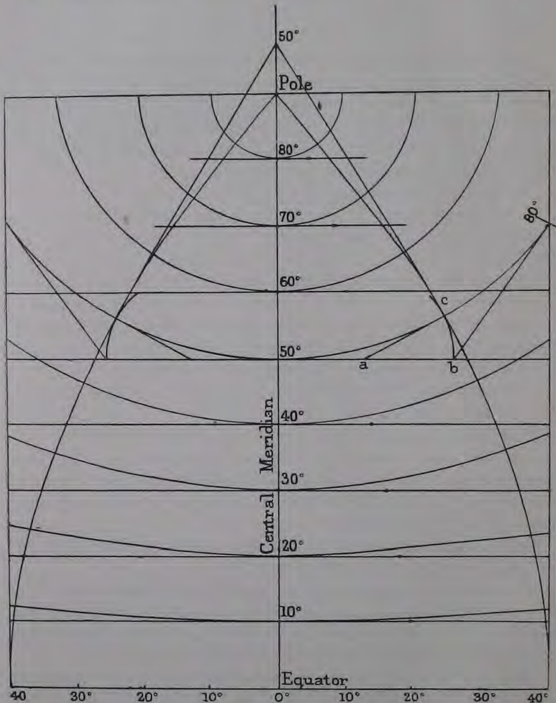
The rectilinear tangential obtains its parallels in the same manner as the polyconic, but the meridians differently by setting off the intervals of longitude to scale, not along the parallels, but along the tangents (see diagram).

In *Fig.* 11 it is required to find the point C on the parallel of 50° where the meridian of 40° cuts it.

The correct distance for 20° of longitude is taken from a table and set off to scale along the tangent to the central meridian ; this gives a centre for striking an arc with the same distance as radius, and where this cuts the parallel is the point required.

When all the points on the same meridian are located and joined they give a curve which will cut all parallels at right angles, thus preserving the true proportion between degrees of latitude and longitude on each successive parallel.

This projection is the one recognized and employed by the Ordnance Survey of England and the Intelligence Department, and was, I understand, first suggested by Colonel A. Clarke, C.B., and afterwards elaborated by Sir H. James, both distinguished officers of our Corps, and who were amongst the most eminent contributors of the century to the progress of surveying.



Rectilinear Tangential.

FIG. 11.

The prime defect of this or any polyconic projection lies in the inequality of the meridional spaces between the successive parallels (owing to the latter being non-concentric), and in the resultant increase in the length of degrees of the meridian from the middle line of the map towards either border; an obvious error is hence involved in the application of the same scale of miles to different parts, but the error is generally so small that it may be practically disregarded.

The projection laid down in the *Text-Book of Military Topography*, Part II., is a development of the simple conical projection, but is comprehensive, practical, and easy of construction.

The projection used by the Indian Survey is of a similar nature, and its use is still further facilitated by tables, which give the lengths of the construction lines in inches for the ordinary scales employed in varying latitudes.

Mercator's Projection.

You are probably all familiar with the name Mercator. It was originally designed in the 17th century by George Kauffman, the latter being the German for "merchant," and was named "Mercator," the Latin term for the same.

Its object was to supply a projection for navigation purposes which would have all the "meridians" parallel to each other, so that a straight line joining two points represented on the map would give the "bearing" a ship would utilize in sailing from one point to the other.

In all other projections it will be seen, if you will take a straight ruler and join two given points lying, say, N.E. and S.W., that as the meridians converge towards the pole the ruler does not cut the meridians at the same angle. If a ship were, therefore, to follow this, the shortest route, it must necessarily keep on constantly changing its "bearing" during its voyage. This is actually done in long voyages, say, from Aden to Australia, and is termed great circle sailing; but for ordinary navigation this is inconvenient, and it is preferred to start on a particular bearing, and sail through to destination without altering it. On Mercator's projection, therefore, the straight ruler joining two places will give that bearing. The ship will then be said to be sailing on a "rhumb" line, and her actual course on the earth will be a kind of spiral curve, but will for ordinary distances deviate little from the great circle or shortest route.

How is such a projection to be obtained with all the meridians parallel?

Suppose the globe as circumscribed by a hollow cylinder which touches the sphere at the equator. Now suppose the globe to become inflated, so that its surface expands uniformly in every direction until it touches the interior of the cylinder; the parallels of latitude would become circles inscribed within the cylinder, and the meridians would be lengthened out into straight lines parallel to each other, and in the direction of their lengths.

If the cylinder were then cut open along one of these meridians, and spread out on a flat surface, the projection would be developed.

Mercator's projection is entirely an artificial one, as it is not seen from any one point, but is the production of what might be seen by an eye carried successively over every part of it. This projection is one used, therefore, in *charts* of the sea and coasts. An illustration is given in *Fig.* 12 of the Planet "Mars" mapped on a "Mercator's" projection.

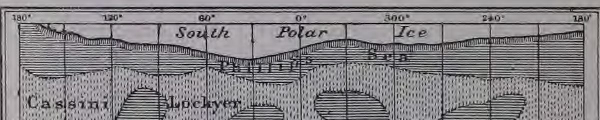


Chart of Mars on Mercator's Projection.

FIG. 12.

In *Fig.* 13 you will observe the form of the same island is fully preserved, but very much enlarged towards the pole ; scales will not, therefore, apply to all parts correctly. On ordinary charts it is usual to eschew scales for this reason, and measure from the degrees and minutes of latitude at the side of the chart (which is graduated in degrees and minutes), and about the same latitude of the distance to be scaled. One minute may be taken as a nautical mile (2,020 yards).

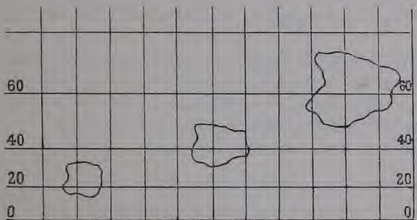


Fig. 13.

Progress in the Middle Ages.

As has been pointed out, Ptolemy worked principally with the stereographic projection. After Ptolemy's time came a long interval of about 1,300 years, during which little real progress was made in the art of surveying.

This may be probably due to the fact that the genuine study of science was perverted into channels of mysticism, such as astrology and the search after the universal solvent, the philosopher's stone, and the elixir of life.

It is curious to note, however, that during this long interval the Arabians became the principal cultivators of practical astronomy, having adopted this science from the Greeks, whom they conquered, and from whom the conquerors of Western Europe afterwards received back their treasure, when their desire for practical study of the subject became re-awakened.

During this interval "Bagdad" became the centre of science, and rose to splendour and refinement.

The Arab astronomer, however, added little to the progress of astronomy; he became, rather, the scrupulous but unprofitable servant who kept his talent without apparent danger of loss, but without prospect of increase.

There are, however, a few important improvements which cannot be passed over, such as the abolition of the cumbrous sexagesimal Greek system of arithmetic and the substitution of the notation which we now employ by using the digits 1 2 3 . . . . . 9 . 0. The Arabs, however, can claim no originality in this, for it came from India.

The Arabs also introduced the measurement of an arc by its sine or half chord of the double arc, instead of the chord of the arc itself.

Many of the terms we still use are distinctly of Arabic origin, such as "zenith," "nadir," "azimuth," "alidad," "almanac."

Some of the stars also retain their Arabic names, such as "Aldebaron," "Rigel," "Fomelhaut."

Modern School.

I must now pass on to the time of Copernicus. He was a native of Prussia, and was born in 1473.

He it was who demonstrated in the 16th century the true principles of the revolutions of the heavenly bodies, and which, shortly speaking, places the sun, and not the earth, as the centre around which we, together with the planets, revolve in our respective orbits.

This great principle was quickly followed by important developments in the hands of Kepler, Galileo, and, finally, the great Newton.

Kepler, in 1622, demonstrated the following important laws :— That

1. The orbits of the planets are elliptical.
2. The areas described or swept by lines from the sun to the planet are proportional to the times employed in the motion.
3. The squares of the times of the planetary revolutions are in the same ratio as the cubes of their mean distances from the sun.

Galileo (an Italian) was the inventor of the telescope about 1609, and he proceeded immediately to apply it to the heavens.

The discovery of Saturn's rings and the four satellites of Jupiter was almost immediately the reward of his activity. A fifth satellite was discovered only about six or seven years ago. It completes its revolution round Saturn in 12 hours!

Galileo also found that Venus assumed exactly the same succession of phases which the moon exhibits in the course of a month.

Ever since Galileo's time the telescope has been a never-ending source of discovery.

Our countryman, Horrox, was the first person who, in 1639, had the satisfaction of seeing a transit of Venus. His great friend, Gascoigne, was the inventor of the micrometer, and was killed at the Battle of Marston Moor.

We now come to the great discoveries of "Newton."

Newton was born in Lincolnshire, Christmas Day, 1642, and died 1727, being buried in Westminster Abbey.

He evolved the mechanical laws of gravitation, and applied them universally.

He conceived the celestial motions to be similar to the every-day mechanical motions which took place close to him, considered them of the same nature, and applied the same rules to each without hesitation or obscurity.

Universal gravitation, shortly stated, may be said to be that every particle of matter in the universe attracts every other particle with a force which is inversely proportional to the square of the distance between them.

Newton showed that the earth's gravity extended to the other planets, and that each was kept in its orbit by their mutual attraction to each other.

These grand principles having been enunciated, all subsequent calculations based on them regarding the positions of the heavenly bodies produced no contradictions, such as were met with by Hipparchus or Ptolemy.

Astronomy passed at once from its boyhood to its mature manhood. It is no doubt conceivable that future discoveries may both extend and further explain Newton's doctrines; but few will dispute that both in generality and profundity Newton's principle is altogether without a rival or a neighbour.

It is curious to note here the opposition at the time that arose in accepting the new principles of Copernicus, Kepler, Galileo, and Newton. Their followers were persecuted abroad; one of them, Giordano Bruno, was burnt as a heretic in Rome; Galileo was prohibited by the Inquisition from defending and teaching the doctrine of the earth's motion, as being contrary to the sacred Scriptures, and he was afterwards condemned for his infraction of this injunction, and forced to abjure on his knees the very doctrine he had taught. One of the Roman cardinals remarked of Galileo's work that it was our business to teach how to go to heaven, not how heaven goes!

Newton's principles were rapidly taken up in England; but in France and Germany prejudice in favour of former theories took some time before they were overcome.

Figure of the Earth.

If we now apply Newton's principles of gravity to the earth, we will find that if there were no rotatory motion, the only figure for the earth, consistent with equilibrium, would be a perfect sphere; but as the earth revolves upon an axis, a centrifugal force is communicated to its components, causing them to recede from the axis and accumulate at the equator, turning it into an oblate figure, flat at the poles and protuberant at the equator.

If you know the size of the earth's diameter in miles, and the rate of rotation, you can easily calculate the ratio of this centrifugal force to that of gravity, the latter having been found, experimentally, to be about 16 feet a second.

Pursuing this train of thought, Newton endeavoured to work out the exact shape or figure of the earth as it ought to be on mechanical principles alone, and he found that the figure ought to be that of an oblate spheroid, and that the ratio of the polar to the equatorial axis was as 229 to 230 (see *Fig.* 14).

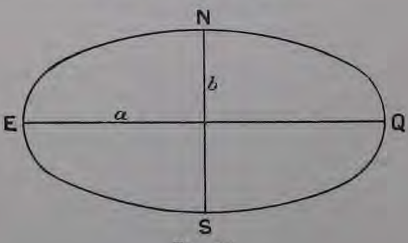


Fig. 14.

This gives an ellipticity $\left(i.e., \frac{a-b}{b}\right)$ of $\frac{1}{230}$, which is too large, being more like $\frac{1}{294}$; but he assumed the earth's diameter to be

7,000 instead of 8,000 miles, which would account for a large part of the error.

In any case, it must be considered a great advance to obtain such a good result in such a simple manner.

At this time, about 1666 (a memorable date for many reasons), there were no reliable values for the magnitude of the earth's diameters, or, indeed, for even its shape or figure.

It was only in 1522 it was first circumnavigated by Magellan, who thus proved practically and beyond doubt that the earth was round.

It is an interesting fact that the name of the only surviving ship of Magellan's original fleet of five which accomplished this historical feat of first circumnavigating the globe was named *Victoria.*

Magellan himself, unfortunately, never completed the journey, being killed fighting the "Phillipinos" on his homeward journey.

The French during the whole of the 17th century actually maintained that the earth was "oblong," not "oblate," their first attempts at direct measurements on the earth's surface to ascertain its figure being very unsatisfactory, and Newton's results, being erratic (from a wrong assumption of the earth's diameter), differed considerably from them.

The French, however, afterwards completed a direct measurement under Picard, with great originality and accuracy, finishing it in 1701.

For some years previous to Newton's time it had been noticed that the pendulum of a clock oscillated more slowly at Cayenne, near the equator, than it did at Paris.

Newton showed that this was in accordance with the laws of gravitation, as the centrifugal force at the equator being greater, the force of gravity was correspondingly diminished, and in proportion to the square of the increased distance from the earth's axis.

If, therefore, we can design an instrument to show us at any place how much gravity increases or diminishes, we can calculate how much the distance from the earth's axis varies, and in this way determine the figure of the earth.

Here then was a grand and simple method by watching the oscillations of a pendulum for determining the figure of the earth.

Pendulums of standard lengths were oscillated in different places, and all tended to establish Newton's idea as to the oblate spheroidal shape of the earth; and it is curious to note that the amount of compression calculated by this method gave $\frac{1}{285}$, a much truer result than was obtained by any other method at the time.

Now, if the earth was a sphere, a section through its centre and its poles would give a circle, and each degree of latitude on the earth's surface would measure the same length.

An inspection, however, of the following table shows that a meridian cannot be exactly a circle, and consequently that the earth is not a perfect sphere :—

Country in which the Measurement was made.	Latitude of the Middle of the Arc.			Length of the Degree in Miles.
	°	′	″	
Peru	1	31	0	68·700
India	9	34	43	68·718
India	12	32	21	68·731
India	13	2	54	68·734
India	16	34	42	68·755
India	19	34	34	68·776
India	22	36	32	68·800
France and Spain	40	0	52	68·983
France and Spain	42	17	21	69·010
France	44	41	48	69·039
France	47	30	46	69·073
France	49	56	29	69·102
France and England	51	15	24	69·117
England...	51	25	18	69·119
Germany	52	32	17	69·132
England...	52	50	30	69·135
England...	54	0	56	69·149
Russia	57	26	26	69·187
Russia	59	13	58	69·206
Sweden	66	20	11	69·274

Consideration will show that in order to cause the progressive increase in the length of a degree from the equator to the pole, the figure of the meridian must be an ellipse, having the polar axis as its shorter diameter. In other words, a longer portion of the perimeter of an ellipse is intercepted by the boundaries of each degree of latitude as you travel northwards away from the longer axis.

Eratosthenes (3rd B.C.) deserves the credit for devising a method of earth or degree measuring, which, in principle, is still used for that purpose.

We take two stations on the earth's surface due N. and S. of each other, and ascertain by *astronomical* observations their difference of latitude.

The exact distance along the earth's surface is then measured by direct means.

We can then from these values easily deduce the exact distance on the earth's surface for, say, 1° of latitude.

According to Eratosthenes, Syene and Alexandria lay on the same meridian, and he calculated by the difference in the lengths of the sun's shadows at each place that there was a difference of 7° 12′ in latitude, or, in other words, about $\frac{1}{50}$ of a great circle. He also took the linear distance between the two places to be 5,000 stadia, and he therefore deduced the earth's circumference to be $50 \times 5{,}000 = 250{,}000$ stadia.

Unfortunately, no record has been kept of the length of a stadia; we cannot now tell whether his results approached the truth, or otherwise.

No meridional degree measurements were made of any note till 814 A.D., when the Arabs, having fixed on a spot in the plains of Mesopotamia, despatched one company of astronomers N., and another S., measuring the journey by rods, until each party found the altitude of the Pole star to have changed one degree. The results were unsatisfactory.

We next come to the year 1615, when W. Snell, a Dutch geometer, conceived and initiated the method of measuring a long line on the earth's surface by methods more or less adopted ever since.

He was the first, also, to elucidate the theory of the refraction of light.

Snell demonstrated that it was not necessary to actually measure a distance along the meridian, as a line deviating therefrom could be corrected to its corresponding length on the meridian if you knew its azimuth. He also demonstrated that it was unnecessary to measure in a straight line between the two stations, but that it may be broken and connected by triangles, which would enable the distance to be computed.

In fact, he was the inventor of our present system of triangulated survey.

His operations extended over the arc between Alcmaar and Bergen-op-Zoom.

He measured a base with a chain, and carried on a series of 33 triangles till he reached his terminal point, observing all three angles of every triangle.

His angles were measured with a graduated semi-circle of 3½ feet in diameter. The Vernier was not invented till 16 years later. This instrument had no telescopes either, so that sights were taken with the unaided eye.

As I have already pointed out, it was necessary to know the azimuth of each ray, *i.e.*, the angle each ray made with the true meridian. So as to compute the projection of this ray along the meridian, "Snell" carefully determined this azimuth astronomically at Leyden, one of the stations of his triangulation, and thus he was able to compute the azimuths of all the rays.

The latitudes of the terminal stations were made with a quadrant of 5½ feet diameter, also without the aid of a telescope. As was natural in the commencement of such an undertaking, Snell's results were not good, as his instruments were rough, and several important points escaped him; but all honour is his due to originating a system which was afterwards universally adopted.

In 1633 Richard Norwood measured an arc from London to York, measuring not by triangles, but along the high road, partly by chain and partly by pacing, making allowances for twistings and turnings. Curious to relate, his results turned out to be remarkably good.

In 1670 Louis XV. asked the French Academy to nominate a man to take charge of a most complete meridional degree measurement.

Picard was accordingly nominated, and he carried out his work in a thoroughly scientific manner.

To Picard we owe the application of telescopes to observing instruments; also the introduction of the "micrometer" and the application of cross lines in the telescope, the intersection of which marked the optical axis.

These inventions made angular determinations really accurate, and advanced astronomy and geodesy far along towards its present stage of perfection.

Picard pursued the general methods initiated by Snell, and his two terminal stations were "Amiens" and "Malvoisine." A base was measured by rods placed end to end; the angle-reading instrument was a quadrant of 38 inches with telescopes, and the scale read only to 1′ of arc.

He obtained the azimuths of his rays by observing the Pole star at elongation.

The latitudes were observed with an iron sector of 10 feet radius divided into 4′ spaces (with telescope). The telescope had cross wires, and was illuminated by holding a light near the object-glass, much as we often do now in the field with small theodolites.

Picard was greatly assisted in his computations by the use of logarithms, which had not been published in Snell's time.

At varying intervals of years several arcs of meridian have been measured in various parts of the world, with ever-increasing accuracy and methods.

The junction of the French and English arcs in 1787 was of especial interest, as it introduced the use of Ramsden's theodolite. Ramsden invented a method of dividing automatically a whole circle by machinery, which ensured great accuracy and minuteness of division, and he also introduced the use of a microscope combined with micrometers for reading them, enabling a circle of 3 feet diameter to be divided up into 10′ spaces, and with the micrometer microscopes reading to 1″ of arc. The success attained in the use of this instrument was regarded as truly phenomenal.

The best machinery of the present day for the accurate dividing of circles, even as small as 5 inches diameter, may be almost considered perfect.

The great Indian arc of 21° 21′, completed about the middle of this century, has always been one of the most important; but the longest measured arc up to date is the great Russian arc. The inscription on the column erected at one of its terminals at Hammerfest, Norway, describes it as follows :—

"The northern termination of the arc of meridian of 25° 20′, from the Arctic Ocean to the River Danube, through Norway, Sweden, and Russia, which, according to the orders of H.M. Oscar I. and the Emperors Alexander I. and Nicolas I., and by uninterrupted labours from 1816 to 1852, was measured by the geometers of the three nations."

It took 40 years to complete this work, which traverses no less than 2,880 kilomètres, or $\frac{1}{14}$th of the earth's circumference.

Dr. Gill, the great astronomer, now at the Cape, sees no reason why it should not eventually be connected with the South African system of triangles, through the Levant, Greece, and Egypt. This would give us a stupendous measured arc of 105° from Cape Town to Hammerfest.

Combining the Russian and other arcs, Colonel A. R. Clarke, C.B., R.E. (who is looked upon, not only in England but abroad, as the first authority on the subject), determined in 1880 the following values for the size of the earth :—

a = Equatorial Radius = 20,926,202 feet.
b = Polar ,, = 20,854,895 feet.

This gives a compression of $\frac{1}{293 \cdot 5}$.

The Ordnance Survey has based their work on a figure of the earth with radii which differ from Clarke's by 146 feet and 338 feet respectively, and for all practical purposes it may be taken as the same.

The radii employed by the Survey of India differ from Clarke's by 3,270 feet and 1,520 feet respectively.

Clarke's figure is considered by both English and foreign authorities to be the most generally acceptable.

The 17th and 18th Centuries.

Before Newton's time progress in the arts was small ; and as art is the parent, not the progeny, of science, progress in the latter was much retarded till about the 17th century, when the arts advanced by leaps and bounds.

Watches were unknown till 1530. Printing and reproduction of maps was only begun about the same time, the first map of England being published in 1520.

Decimal arithmetic was invented by Stevin at the end of the 16th century, and at this period navigation had to depend on the use of the compass, the cross staff or astrolabe, and rough tables giving the sun's declination and corrections for the altitude of the Pole star.

Intervals of time were measured with hour and minute glasses.

As has been said, there was little advance up to this period in map-making since Ptolemy's time.

After Newton's time geodesy was based on sound principles, and rapidly grew in accuracy and development.

The credit of originating and carrying into effect the first tangible project for a systematic topographical survey is to be divided between two R.E. officers, Lieut.-General Watson and General William Roy.

They started the first British survey in 1747, commencing in the Scottish Highlands, where a want of topographical knowledge very much hampered military operations.

This eventually led to greater things, till it was decided to institute a triangulation in the neighbourhood of London, with a view to connecting it later on with the French triangulation across the Channel.

It is unnecessary for me here to follow the history of this great work, which was commenced about 1783, and which gave rise to the Ordnance Survey. The result of its mapping you are all familiar with, and which has been equalled, if not surpassed, by the magnificent development of the Survey of India and the Trigonometrical Survey in South Africa, the greater part of which work has been so intimately identified with the officers of the Royal Engineers.

The 19th Century.

I now pass on to our present stage in the practice of surveying.

The general principle aimed at in geographical surveying at the present time is to ascertain by various methods the accurate latitude and longitude of a few selected and evenly distributed points in the area to be surveyed, and by the assistance of these accurately fixed points to fill in the topography by more approximate but sufficiently accurate methods for practical purposes.

A proper projection having been drawn, we can then plot our fixed stations by their ascertained latitude and longitude, and fill in the map detail round them.

The accurate latitude and longitude of fixed stations may be ascertained either by triangulation with theodolites, or by astronomical observations, or by a combination of both. The topography and real mapping of the country is almost entirely filled in by the plane table and clinometer. This is very briefly our accepted ordinary British method of working everywhere out of England.

It is a method which has turned out the most satisfactory results under all kinds of conditions of time and circumstances.

The latitude and longitude of the fixed stations need not necessarily be obtained astronomically.

The system of triangulation avoids all that, except at one station in a rapidly triangulated system, usually the initial station, where it is necessary to observe its astronomical latitude, the azimuth or bearing of one of the rays, generally the base line, and to assume the best value for longitude you can arrive at.

The latitude and longitude of all the remaining stations can then be computed throughout the triangulation, no matter how extensive, with the utmost precision.

To instance the extraordinary elasticity of this method of surveying, and its adaptability to varying circumstances, I will now show you two examples of triangles worked under totally different conditions (see *Plate* XI.). Here, in the triangulation of India, you will observe lines of triangles worked for hundreds of miles with every care, plenty of time, and with very large and refined instruments requiring built-up platforms to observe from and to, with correspondingly marvellously accurate results, perhaps to less than 1″ of arc, or 30 yards. Now see *Fig.* 15.

This was a triangulation carried out by the Afghan Boundary Commission under very difficult circumstances while on the march.

The starting point was Ibrahimabad, the latitude and longitude of which were known. The instruments were light field theodolites, and the tops of the hills had to be observed to without marks or signals of any sort.

Nevertheless, this triangulation was carried out, 310 miles in 19 days, or an average of 17 miles a day. It was considered that the longitude of "Kuhsan" thus found was not in error more than 5″ of arc, or 150 yards.

This was rapid and accurate enough to satisfy the most fastidious.

It would, of course, be quite exceptional to obtain such accuracy always under these circumstances; but it shows the great possibilities there are in front of this class of work.

Hitherto the determinations of the latitude and longitude of fixed stations by astronomical observations alone at different stations found much favour; but the uncertainty in the accuracy of the results from astronomical observations must always remain an unsatisfactory element as compared with the certain and reliable results to be obtained from the triangulation method.

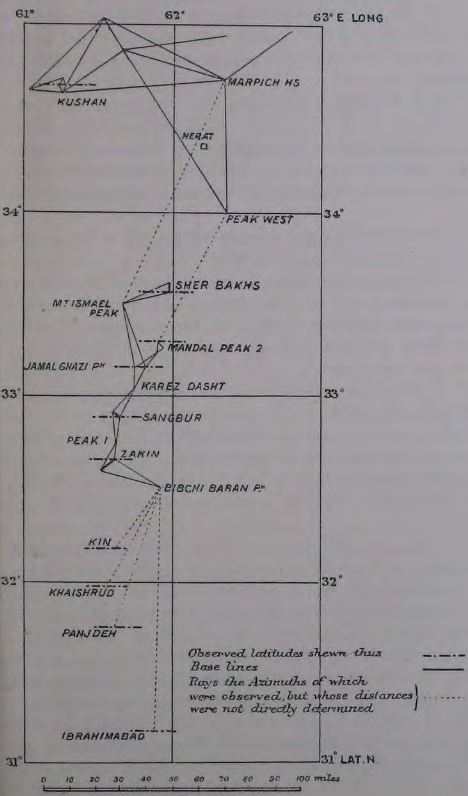


FIG. 15.

Differences of longitudes between land stations can seldom be obtained with any degree of accuracy except by telegraph.

Direct observations for longitude with ordinary light field instruments have occasionally been obtained, giving reliable results to a limited extent, *i.e.*, with a very large margin of possible error; but the results in general have turned out so unsatisfactory and difficult to obtain that surveyors, as a rule, prefer to do without them altogether.

To obtain longitudes, therefore, with any certainty, where there is no telegraph, we must frequently fall back on triangulation.

To the single *explorer* triangulation is unsuited (even if he is qualified to undertake it), as but very rough indications of the localities in an entirely unknown country is all that is demanded of him.

This information he can readily obtain by a few approximate astronomical latitudes and azimuths.

In the not far distant future, however, the explorer will no longer be in existence, and a demand will and must come for more deliberate and accurate surveys of those countries which have already been explored, and now require their topography to be fairly accurately depicted.

Such a survey should, I think, be based whenever possible on the triangulation method, and have its topography plane tabled in.

Believing, as I do, that the future will demand a large amount of this class of accurate but economic surveying, I have endeavoured, I hope with some success, to bring it (with small scale plane table work) prominently forward in the instruction here at our headquarters.

Where our curriculum must have such a far-reaching effect throughout the Corps, I am in hopes that, therefore, my ambitions will be fulfilled, and that the officers of our Corps will be fully prepared to take their part in the future development of survey work with the same credit as they have always done in the past.

I do not wish to depreciate the value of astronomical observations. They are as necessary as ever, and must be taken with greater skill and care than ever, but I would deprecate the acceptance of the position of any place as accurate merely because it is marked as determined by astronomical observations. The latter are only reliable when obtained by careful and skilful observers, and a good deal of "faith" must be exercised in placing reliance on their accuracy.

I have for inspection the originals of the field sheets of a rapid survey in South Wales, where some of our young officers completed about 200 square miles in three days on a half-inch scale. Had we but recently had this class of map in certain portions of South Africa, it would, I venture to think, have lightened our difficulties there considerably.

I would draw attention to the great assistance we can all get now from the new text-book of military topography brought out only last year. It is, in my opinion, an immense improvement on former text-books.

I am an advocate for obtaining every assistance one can from improved instruments, or from the use of tables or forms, either for recording observations or for computation purposes, and also to assimilating our methods as far as possible at our various centres of survey, such as the Ordnance Survey, Intelligence Department, and Survey of India. For many years surveyors have had to contend against great differences of, even, principle, but I hope now these differences are gradually disappearing.

I know there are those who still consider every officer should be able to work out formulæ at any time, and compute with the least possible assistance from tables and forms; but when you consider that many of our officers are called upon to undertake survey work suddenly after many years have elapsed since they practised it, you will see how necessary it is for them to have every facility for working correctly, and for reminding them of the proper method to work on. I find that with a large number of officers they are able to get through work fairly quickly and accurately if they use forms and tables, while without such assistance many of them would fail altogether, and the majority would get absolutely incorrect results.

After all, our object is to get good work done quickly and accurately, and not to provide abstruse mental exercises every time the surveyor wishes to obtain a result. Our S.M.E. tables and forms for the use of R.E. officers have been compiled on these principles, and approved of by the authorities. Those for triangulation work are similar to those used in the Survey of India, but are computed up to 60° instead of 40° of latitude, and are in a more compact form.

The astronomical computation forms and angle book are new, and have been adopted by the Ordnance Survey for the use of their field sections now in South Africa.

I will now point out to you various instruments, which I think will help you to form an estimate of the stage of progression at which we have arrived.

INSTRUMENTS, ETC.

5″ micrometer microscope transit theodolite.
5″ Vernier transit theodolite (service instrument).
5″ ,, ,, ,, (larger telescope).
3″ portable transit theodolite (Troughton & Simms).
3″ ,, ,, ,, (Casella).
24″ × 18″ plane table and equipment.
Tangent clinometer (Indian pattern).
Reconnaissance plane table (service pattern).
Cavalry sketching board (service pattern).
Watkins' mirror clinometer ,,
Pocket prismatic luminous compass (service pattern).
Pocket luminous compass (service pattern).
Aneroid 3″ aluminium.
,, 2½″ (Short & Mason's pattern).
8″ aluminium sextant and artificial horizon.
4″ tacheometer.
15″ gradiometer level (service instrument).
9″ Cooke's reversible level (service instrument).
Dumpy level.
Y level.
De Lisle clinometer.
Prismatic field glasses (Zeiss pattern).
Solar compass.
Perambulator (old pattern).
Miniature pocket paint box.
Shortrede's table of logarithms (giving the log. of sines, tangents, etc., for every second).
Heliostat.

I would draw your attention to the 24″ × 18″ plane table equipment, to which I always advocate the addition of the tangent clinometer (Indian pattern). The light reconnaissance plane table is intended to be of a more portable kind, and to be carried by an officer when travelling on horseback. It is intended to do work for which the cavalry sketching board furnishes too small an area, such as the reconnaissances of positions.

The above plane tables are now service instruments, and are supplied from Woolwich.

The excellence of work in the construction of the 5-inch micrometer microscope transit theodolite is worthy of attention, and this instrument for ordinary field work will be hard to beat. I have never yet met the surveyor who has once used micrometer microscopes ever care to use Vernier reading instruments again. The aluminium star sights I have had put on the telescope are, I think, a valuable addition to the celerity of observation.

The tacheometer is an instrument much used abroad, especially in Italy, but in England we do not favour it much, as we can practically get the same results by the use of the horizontal circle of our theodolites — a system of measuring distances which is better known as "The Bar Subtense" method.

In connection with this I may mention that I have long advocated a more general appreciation of this latter method as a substitute for the slow and laborious system of "chaining." The efficiency, both in economy and accuracy, of this method has quite recently been fully demonstrated by the completion of an extended survey in Chili for the Government of that country. It was executed under the direction of Professor Bertrand, of Santiago, entirely by traverses carried out without any system of triangulation, all the distances being measured on the "Bar Subtense" principle as taught at the S.M.E.

The prismatic binoculars are a distinct advance on the familiar direct vision species, but they can never equal a telescope of the same focal length except in convenience of portability.

The De Lisle clinometer is eminently useful in prospecting for hill roads, and is much used in India.

The solar compass is much used in America, but has never found favour in England.

The "gradiometer level" is an instrument lately introduced into the service in "lieu" of the 15-inch Cooke's reversible level.

It has the advantage that by means of a micrometer or drum-head reading it can be set at any desired gradient, and is useful in running sections quickly or in laying "lines of fire" or drains, etc., with given depressions or elevations.

The "Heliostat" is sometimes invaluable in geographical surveying. Although the "Heliograph" is the service instrument for signalling purposes, and is probably more convenient for short distances, it cannot compete with the "Heliostat" for a steady light on very long rays. For survey work I think the heliostat indispensable.

For astronomical field work on land the theodolite, as opposed to the sextant and artificial horizon, is gaining ground every year. Improvements in manufacture have now made theodolites which can give results as accurate as the sextant, and yet are almost as portable, and they have undoubted advantages in observing for azimuth angles which are absolutely indispensable in land surveying. Theodolites are also simpler to observe with in unpractised hands.

I cannot close without noticing two comparatively recent and probably important adjuncts to surveying in the adaptation of photography to its uses. The advantage of photography in the reproduction of maps has long been established.

I must leave you to study for yourselves the very interesting branch of survey of the heavens by photography, which has enabled stars and planets to be developed and discovered on the photographic plate that are absolutely invisible to the eye, even with the assistance of the largest telescope in existence. We had an instance of this only last year when a ninth satellite to Jupiter was discovered in this manner, but has never yet been seen, even through a telescope.

The two adaptations of photography I refer to are:—

1. The determination of longitudes, by Captain E. H. Hills, R.E.
2. The photo-theodolite, by J. Bridges Lee, Esq., M.A.

Time will not permit me to go into details of these adjuncts to surveying, but a few points regarding them are worthy of notice.

The determinations of longitudes by direct astronomical observations with field instruments has generally proved unsatisfactory. By using Captain Hills' instrument the skill of the observer is reduced to a minimum, merely requiring a proper selection of stars, which, with the moon, are successively exposed to the same fixed photographic plate at certain intervals of time. This plate when developed gives sufficient data for computing the exact longitude of the place of exposure.

The error of such observations, Captain Hills states, can be kept within a margin of four seconds of time. This is a great advance in accuracy on other known methods with portable field instruments.

The photo-theodolite of Mr. J. M. Bridges Lee is intended to take photographs of the surrounding country in any given direction from a station the position of which is already known. Then the resultant photographs from any two known stations enable all visible points and detail to be plotted from them on a map to any scale.

In fact, the work that is now done on a plane table can be done from the photographic plates or prints at leisure, and in a possibly more convenient place than on the top of a hill.

The process of plotting will be better understood from the photographs of Trafalgar Square (see *Plate* XII.).

The chief improvement introduced in Mr. Lee's instrument is that each plate has its own angular scale developed on it with its zero on a central vertical hair line, and also the magnetic bearing of any point can be determined by the upper circular scale.

I think this system has possibilities in front of it, especially under circumstances where the least possible time is available for the actual field work, and more time can be devoted to the plotting, etc., such as when an explorer reaches the summit of a very high or distant hill, and is forced to commence the descent almost immediately after arrival at the summit. I can also imagine such circumstances occasionally in a theatre of war or in an unfriendly country.

I don't think, however, the system should be looked upon as a rival to the plane table, but rather as an adjunct to it under special circumstances.

Large areas in Canada have been already surveyed on these principles with great success.

I had hoped to say something on the development of the telescope, but regret time will not permit me. I can, however, show you a representation of the most recent and largest refracting telescope in the world, now being prepared for the great Paris Exhibition of this year.

The principle of it is that the telescope itself is *fixed* in a horizontal position, and there is a large plane mirror placed in front of the object-glass, which, moving by clockwork, always keeps reflecting the same star or planet into the telescope.

The part of the apparatus with the plane mirror is called the "siderostat," and can, of course, be adjusted so that any particular part of the heavens can be reflected into the telescope.

The mirror is 6′ 6″ in diameter. The object-glasses are in two parts (one crown and one flint), and are 4′ in diameter, and have a focal length of 328′ (or 109 yards about). At the eye-piece end arrangements have been made for throwing the image on the screen of a large theatre capable of holding 4,000 persons.

It is calculated that this telescope will enable us to see the moon as if it were only 50 miles off, and that an object only 1 mètre square might be seen.

I hope many of you will have the privilege and pleasure of exploring our satellite at such very close quarters.

PAPER II.

PROGRESS IN BARRACK DESIGN.

Delivered in the form of a Lecture at the S.M.E. on February 15, 1900, *by*

MAJOR E. H. HEMMING, R.E.

PART I.—HISTORICAL.

SPACE will not, of course, permit of my following up all the steps, in what is now ancient history, which led up to the present state of our ideas on this subject, and a brief sketch of how and when barracks and hospitals first began to assume modern proportions and details is all I can attempt. Introductory

There is unfortunately no room for doubt that in the first half of the present—or shall I be safer if I say the first half of the nineteenth century—the housing of the soldier was deplorably neglected, and enquiries instituted just before and just after the Crimean War by several Parliamentary Committees and Commissions, both at home and abroad, tended to show that the high mortality in the army was due in a great measure to that neglect, or, in other words, to pulmonary diseases caused by the overcrowding of men in more or less insanitary barrack-rooms.

Thus we read that in 1820 in the West Indies the men slept in hammocks touching each other; and at the same time in England soldiers were accommodated in beds arranged in double tiers.

Next, although in 1838 the regulations enacted generally that barracks were not to be overcrowded, it was not until the publication of the Engineer Regulations of 1851 that a definite cubic space per man was fixed. The nominal rates per individual soldier then laid down ranged from 450 cubic feet for barracks at home to 900 cubic feet for hospitals abroad.

Lord Monck's Committee.

Four years afterwards, in 1855, the first important investigation into the existing conditions was made by a committee under Lord Monck, the evidence then collected pointing to the necessity for better accommodation for the comfort and convenience of soldiers, and for the creation of a higher tone of social habits amongst them.

The recommendations of this notable committee in their general tenour bear a strangely close resemblance to those of the committees of to-day, and the surprising part of the history is the time which some of these recommendations have taken to bear fruit. But the cry is ever the same, and every modern improvement is prompted by the same motive, viz., the desire to produce an improved tone in the *personnel* of the army, and with it both better physique and general health, and consequently better fighting material.

This is a principle, however, which there is a possible danger of vitiating by carrying matters to extremes; and we must be on our guard, in endeavouring to satisfy the public demands for the soldier, that we do not overstep the mark and spoil our army in the endeavour to attract recruits to it. That we have not reached this stage yet everyone must admit who has given a thought to the present war in the light of military history (and which of us has not?), and realizes what our soldiers have done in the face of modern magazine rifle fire.

Next in importance, perhaps, to the evidence relating to the overcrowding of barrack-rooms were the revelations regarding the accommodation of married soldiers. It was a common practice then for soldiers' wives to live in the barrack-rooms with their husbands, in the proportion of 6 per cent. of the total strength, no means of separating the married from the single men in the room being allowed beyond a curtain round the bed or blankets hung across the room on a cord. In some cases, we read that even this apology for decency was dispensed with.

In other cases, again, married people were placed in barrack-rooms apart from those of the single men, but with several families in the same room. And although I have been unable, as I feared I should be, to find any plan indicating the appropriation of a barrack-room in either of these ways, I have, in the course of my enquiries, come across plenty of evidence from pensioners now living, not only of the existence of these abuses then, but of their continuance to a much later date :—cases both at home and abroad being authenticated as late as the seventies.

While the chief recommendations of Lord Monck's and other subsequent committees were confined to remedying these two great evils, viz., the overcrowding of single men and improper housing of married soldiers, by the laying down of reasonable cubic space and superficial areas for each individual, and in arranging for the construction of separate married quarters, other minor matters did not escape their notice.

Amongst these we find suggestions for the introduction of such now familiar institutions as regimentally served canteens, ablution rooms with foot-baths, wash-houses for the use of soldiers' wives, workshops, ball courts, urinals with divisions, lighting by gas, and even day rooms and cubicle partitions.

Lord Monck's committee also advertised and offered prizes for the best plans of a model infantry and cavalry barracks prepared by civil architects, the prize winners to superintend the erection of the next two barracks built.

The prizes were duly awarded, although none of the plans sent in were considered good enough for a model, and all were too costly for War Department purposes.

Mr. Wyatt, the cavalry prizeman, for elevations and details only of the Knightsbridge Barracks, and for plans of a cavalry barrack at Nottingham, without superintendence, received altogether £5,420; while Mr. Morgan, the infantry prize-winner, who afterwards prepared plans for and superintended the construction of Chelsea Barracks in conjunction with the War Office, received for his work £8,629.

That this, however successful, was a very extravagant method of procedure is apparent from a comparison of the cost per man of the barracks at Chelsea and that of others, carried out by the War Department alone about the same time.

Royal Commission.

In 1857 a Royal Commission was assembled under the Right Honourable Sidney Herbert to make further enquiries on this subject, and from their report, presented to Parliament in 1858, we arrive at the startling result, obtained from statistics, that the death rate among soldiers in peace time was approximately twice as high as among civil town and country populations of the same ages; and I may mention that whereas the mortality in the army was then recorded at 17·5 per mille, it was, in 1897, as reported by the Army Medical Department, only 3·42 per mille.

Although, of course, the army to-day is composed of younger men than it was 40 years ago, and in other ways also the conditions are not parallel, still the difference in the death rate is sufficient to show a very great improvement in the health of the troops, a result for which it is only fair to give the improvement in barrack accommodation the chief credit.

The past 50 years have also seen a very marked advance in the housing of working men, owing partly to the study of hygienic conditions, and partly to the spread of education and the fuller recognition of the lower classes; and if the progress in barrack accommodation appears to have been more rapid than in the case of civil buildings, it must be remembered that not only were the military improvements commenced at a later date, but that the state of affairs in barrack buildings was, to start with, an even more parlous one.

In the recommendations of the Royal Commission we have definite allowances of cubic space laid down for every soldier in barracks or hospitals both at home and abroad. These are given in the following table alongside of those that prevail to-day:—

	Cubic Allowances.			
	Barracks		Hospitals.	
	Home.	Abroad.	Home.	Abroad.
Laid down by Royal Commission of 1857	600	800	1,200	1,500
Authorized in 1900	600	1,000	1,200	1,600

From which it will be seen that whereas the English allowances have never since altered, those for tropical countries have been only slightly increased in a period of 43 years.

Whether these allowances are sufficient is, in the opinion of medical men, doubtful; but so long as we have as clean a bill of health in the army as we have now, financial considerations will probably stand in the way of more liberal accommodation.

Based on the above scale, the collective cubic contents of all the barracks in the United Kingdom were found to fall short of the necessary accommodation for the troops by about one-third: and it is especially interesting, from a sapper point of view, to note that Chatham was in this respect the worst of all the stations in the British Isles. There were, of course, individual cases which were more flagrant, both at home and abroad; some where a man's allowance of air was reduced to 250 cubic feet, and others where the beds when let down covered practically the entire floor space. One or two examples of this kind will be found further on among the plates illustrating the actual design of barrack-rooms.

The amount of floor space and the space between beds, although commented upon as important considerations directly affecting the health of the troops, do not appear to have been definitely laid down until a much later date—being, as in fact they are still, the outcome of other factors, such as height of rooms, and lengths of wall space occupied by beds, windows, and accoutrement racks—taken in conjunction with a fixed cubic allowance.

Of other less important points covered by the recommendations of the Royal Commission—which, of course, included the improvement of married quarters, and otherwise followed generally the lines of Lord Monck's committee—perhaps the most useful was the necessity for the proper choice of sites and the utilization of medical assistance to this end.

Barrack and Hospital Improvement Commission.

A body was next formed under the name of the Barrack and Hospital Improvement Commission to consider the recommendations of the Royal Commission in detail, and the noble sum of £100 per barrack was placed at their disposal to meet urgent sanitary proposals.

This amount was found, of course, totally insufficient for the purpose, the Commission stating, in fact, that "so far indeed as concerns the health of the troops, almost every barrack and hospital we have visited can be considered in no other light than as never having been completed."

Their final report, which was presented to Parliament in 1861, besides dealing with the sanitary conditions of each establishment, and the works and improvements considered necessary in every case, also laid down certain hygienic principles governing the proper construction of barracks, hospitals, and their accessories, which form the basis of those we follow at the present time.

Army Sanitary Committee.

In 1862 the Barrack and Hospital Improvement Commission was constituted a standing committee to continue the same work, and in 1865 their title was altered to that of the "Army Sanitary Committee," which remains a very active body to this day.

Their present duties, as far as barrack design is concerned are :—

(i.). To report on all new sites and on block plans of new barracks—making whatever inspections may be necessary.

(ii.). To report on all type plans, especially with reference to sanitary details.

(iii.). To report on all new principles of sanitary construction or fitments.

The space at my disposal prevents my touching upon the intervening pages of the history of this subject, but it will have been gathered that the period 1855 to 1865 was that in which the great effort for better things was made by the assembling of the Commissions to which I have alluded ; and the tale of years that followed is chiefly one of how, as money was forthcoming, the recommendations of those Commissions were put into tangible form.

And although these suggestions were made primarily on sanitary grounds, and the improvements to barrack blocks were rightly considered the most essential, it is interesting to find that the betterment of the minor buildings or accessories has so exactly kept pace in the succeeding years with that of the men's accommodation, pure and simple, that the relative proportion of cost of barrack blocks to recreation and other buildings is exactly the same to-day as it was half a century ago. This ratio is approximately 1 to 2—*i.e.*, if a battalion barrack complete costs £120,000, the men's barrack blocks alone will cost £40,000, and the remaining buildings £80,000.

Part II.—Design.

The technicalities of barrack design as a modern subject include, as I have before mentioned, much besides the actual planning of barrack and hospital buildings, inside and out ; and for purposes of this paper I have divided these considerations into the following heads, viz. :—

(i.). Sites, including drainage, sewage disposal, and water supply.

(ii.). Disposition of buildings on sites or block plans.

(iii.). Design of barrack buildings, including ventilation, lighting, warming, etc.

(iv.). Design of hospital buildings.

(v.). Constructional details.

(vi.). External treatment.

(i.).—SITES.

Generally speaking, *any* site, whether for civil or military buildings, should be reasonably adaptable, *i.e.*, without any exceptional financial outlay, to the purpose required—both in its natural formation and in its relation to the immediate surroundings. General Conditions.

In the case of sites for barracks and hospitals, however, the more special and technical considerations which require our attention are those of defence and sanitation.

Of the former, which are chiefly confined to barracks abroad, I have little to say here, although the proper study of these considerations is none the less the natural and essential duty of the sapper, while any neglect in this respect is calculated to make him famous at some future period of history.

Sanitary considerations, on the other hand, are far more universal in their application, and as touching the lives and health of our troops in peace as well as in war, require even more careful attention, and cover a far wider field of study.

In the case of a site of any material extent or importance, some preliminary enquiry will be necessary as to the climatology and meteorology (*e.g.*, rainfall, prevailing winds, etc.) of the locality, as well as the possibilities of water supply, and the health statistics of the neighbourhood. Also, a visit to the site in the evening when conditions are favourable to fogs and mists should not be neglected.

The desiderata of a good site are briefly—that it should be open, though not necessarily devoid of trees—fairly elevated, and freely exposed to the atmosphere, although protected from cold or unhealthy winds—the ground around should have a fair fall to facilitate drainage, with natural drainage outlets—a dry and porous soil—a healthy climate—also freedom from any undrained marshy land, deep ravines, foul or stagnant water, and nuisances generally.

Soils are a most important feature in the choice of sites, and call Soils.

for more serious consideration than perhaps they always get. Gravel, sand, and chalk form as a rule good sites; granites, clay, slate, limestones, or sandstones are all more or less dense, and consequently do not, unless disintegrated or fissured, absorb moisture. Dolomites and magnesian limestones, however, often contain a good deal of water. Loams, marls, and stiff clays are not good soils for building purposes, and require to be thoroughly drained artificially in one way or another in order to be healthy. They have, however, the advantage of not absorbing leakage from drains in the shape of deleterious gases and liquids; and alumina, the chief constituent of some of them, also has the further advantage of acting as a deodorant.

The worst soils, though from their nature some of them are, unless carefully examined, liable to be mistaken for good ones, are shallow beds of gravel or sand overlying clay, reclaimed lands from rivers, alluvial tracts, and generally, artificially made up soils.

Subsoils.

Subsoils are almost as necessary a study as surface soils, as it is equally essential that both should be clean and not fouled by sewage, refuse, or other impurities.

The depth below the surface of what is called the ground water regulates to an important extent the dryness of any site, and this should be ascertained by digging trial pits. This ground water should be both deep *and fairly constant in level*, so that in permeable soils, the dangers attendant on the movement of harmful gases may be minimised.

Some useful tabular arrangements of soils in order of healthiness and relative power of retaining heat, and showing the extent to which they lend themselves to evaporation and percolation, were given in some lectures on army sanitation, delivered at the S.M.E. by the late Sir Douglas Galton.

It may be generally assumed that practically no site will be suitable for building purposes unless drained, and that most, if not all, buildings will require a protecting layer of concrete in or below the ground floor, and in some cases both. When I say below the ground floor I refer to cases, chiefly abroad, in malarial countries, where it is essential to keep all buildings 3 or 4 feet clear of the surface.

Drainage and Sewage Disposal.

Besides the subsoil drainage, or drainage of sites before anything is built on them, of which I have spoken in brief only, there remains, of course, the ordinary and more familiar "surface and foul drainage" connected with finished barrack or hospital buildings, and the ground immediately around them.

Connected also with this barrack drainage is the kindred subject of sewage disposal, and these generally require to be considered together.

On barrack drainage we have an excellent manual for our guidance, and although the subject generally is considered to be a complex one, and often left to specialists to deal with, the principles which govern it, viz., the immediate removal of foul matter and the prevention of foul gases, are not difficult to apply in the systems we usually employ.

The following are briefly the practical requirements of any simple barrack drainage scheme:—

(*a*). Even and good gradients.

(*b*). Straight lines, not running under existing or sites of possible future buildings.

(*c*). Manholes or inspection chambers at junctions and changes of direction, to give ready access for cleaning.

(*d*). Thorough ventilation of all parts of the system from the lowest to the highest, *i.e.*, fresh air inlets at the roots, so to speak, and ventilators at the tops of the branches.

(*e*). A good flush, either natural or artificial.

This flush was formerly often effected by allowing the natural rain-water to run into the foul drains; but owing to the danger of improper connections and the intermittent nature of the rainfall, this system is not to be recommended. In old barracks there was, a year or two ago, no commoner fault, though a very easily remedied one, than to find the rain-water pipes running down into the ground and connecting directly with foul drains, instead of discharging over trapped gullies. In this way the rain-water pipes acted as ventilators to the drain, and as often as not passed within a foot or so of a bedroom window.

Nowadays, therefore, it is usually the custom to separate the foul from the rain-water system as far as possible, there being, as a rule, some useful purpose to which to put the rain-water, *e.g.*, fire, washing, artificial flushing, or general supply, while at the same time it is nearly always desirable to keep the sewage undiluted with water and small in volume.

This brings us to the consideration of sewage disposal.

Where public sewers exist the problem presents no difficulties, Sewage Disposal.
but on country sites with no natural outlet, recourse must be had

either to sewage farms or to biological purification, accompanied or not, as circumstances may dictate, by earth conservancy. In either case we have to rely on friendly microbes, the micro-organisms of soil that we may call nature's scavengers, through whose good offices the organic matter continually being received on the earth's surface is broken down and restored to its original elements.

These systems of biological purification, as they are called, employ the agency of two separate families of bacteria, known as *anærobic* and *ærobic* micro-organisms, *i.e.*, those that work respectively without or with air or oxygen.

These two families of bacteria, roughly speaking, perform the two necessary processes by which sewage is rendered innocuous, viz. :—

(1). The liquefaction of the sewage.

(2). The nitrification or mineralizing of this liquid.

In the septic tank process, one of the most modern of these systems now in vogue, and in other similar installations, these two results are achieved separately.

The first, or liquefaction stage, takes place in a closed chamber or modified cesspool, wherein the actual sewage constitutes the necessary matrix suitable for the encouragement of the liquefying organisms.

The second, or nitrifying process, is brought about by passing the liquid through ærated filters filled with some *finely* divided material, and so exposed to the greatest number of ærobic microbes.

The biological process and these special forms of applying it, have been found suitable for the purification of domestic sewage, and will no doubt be greatly used in one form or another in the near future.

Water Supply.

The conditions of a good water supply for troops are that it should be first, pure, and secondly, plentiful. The freedom from contamination, including the careful inspection and, if necessary, guarding of the gathering ground, and the cleanly transport of the water thence to the barracks, require the most vigilant attention, and will do more to the end in view than any subsequent systems of sterilization or filtration, such as are commonly relied on in other countries.

Rules are laid down for our guidance in determining the extent of the water supply of a barrack, based on the assumption that two days' reserve supply shall always be available in case of a breakdown.

It is our custom to provide this reserve in small cisterns in every building, which act to a certain extent as water waste preventers, but which are in some measure open to contamination, and from their great number are less likely to be properly cleaned than one large reserve tank.

Personally, I am inclined to favour a single elevated reserve tank system, and allow everyone in barracks to draw directly from the main, the reserve tank being switched on by a valve should the supply at any time fail. This system also gives a large body of water, with a head corresponding to the height of the tank, for use in case of fire, either alone or in addition to a fire service from the main.

Such a fire service may either be combined with the domestic supply or preferably form a separate system, with hydrants placed at such intervals as will enable them most economically to command all the buildings intended to be protected.

(ii.).—Block Plans.

Following the considerations affecting the choice of a site suitable for barrack buildings, the next in order are those which govern the disposition of these buildings on the ground, or the making of the block plan.

Our army is the most cosmopolitan in the world.

The aspect and *orientation* of buildings, to use a word which, though not strictly a correct one, has of late become common parlance, will be governed not only by the purpose which the buildings are intended to serve, but also by their geographical position. Aspect.

Thus, whereas, in the case of barrack blocks and hospital pavilions in tropical countries, we have to protect them and their occupants against the direct rays of the sun, in temperate climates we court as much of nature's purifiers and deodorisers, air and sunshine, as possible.

Hence, in the British Isles barrack and hospital blocks are now generally built with their longer axes north and south, *i.e.*, with their windows facing east and west, by which we get, both on the buildings and on the ground between them an even distribution of sunlight and air without excessive glare or chill, and consequently a fairly equable temperature throughout the rooms.

In tropical climates, on the other hand, the comparatively horizontal rays of the morning and evening sun slanting directly into the windows have to be avoided, and the orientation of the buildings modified accordingly.

These general principles do not, however, apply to such buildings as stores and private quarters, in quite the same way as in the case of public rooms with windows on both their long sides. In the case of quarters, the pleasantest and most cheerful aspects should be chosen for the most occupied rooms, which on hygienic and æsthetic grounds alike require a brighter light than others.

Prevailing winds, especially in hot climates, will also, of course, temper the above rules, and the exigencies of particular sites and the proximity of existing buildings, if there are any, will also require to be taken into account.

Due consideration being given to the foregoing factors, the following brief rules will be found a useful guide in determining the relative positions of regimental barrack buildings with regard to one another, as well as in relation to parades and communications.

Disposition of Barrack Buildings.

Barrack blocks should be arranged together, and adjacent to—preferably facing—the parade, and in the case of mounted units convenient to stables also, both barracks and stables being approached past the guard-house.

Cookhouses, baths and latrines, and dining-rooms should be close to barracks, and not more in evidence than need be.

Married quarters, with laundry and drying ground, should be in retired positions, and as well screened from the single men's quarters as the site will allow.

Recreation establishments and canteens should be convenient for both married and single men, preferably near each other without being absolutely contiguous, with other means of recreation, such as fives court and shooting gallery, at hand.

The sergeants' mess is a rather important building, and should have a good frontage and be convenient to the quarters, both married and single, consistently with not being too near the men's barracks or the regimental institutions.

Senior N.C.O.'s naturally do not wish to be too near the men's canteen; and the sale of liquor to men from sergeants' messes, when canteens are closed, is not an unheard-of, though much to be discouraged, practice.

C.O.'s quarter, officers' quarters, and mess should have the best available frontage, if possible on a private road not used as a thoroughfare by the men, and with their stables conveniently placed. Near these last may also be the regimental transport stables and wagon sheds, generally on a road, and under the eye of the guard.

The quartermaster's quarter may be near or in line with the officers' mess, and, *cæteris paribus*, conveniently close to the regimental shops and stores.

The latter and other similar accessories should be arranged on roads for the easy service of carts, and otherwise placed as conveniently as possible for the purpose for which they are intended, coal yards being especially located centrally, to avoid unnecessary fatigue duties.

The guard-house, combined with regimental offices, such as orderly-room, etc., should be at the entrance to barracks, and should overlook them and the parade; at the same time, they should not be too far from the officers' quarters.

The regimental sergeant-major should also be near the guard, and the remaining warrant officers, such as bandmasters and school teachers, with or near the schools, in the vicinity of the married quarters.

The parade should be of at least the size necessary for the forming up of the unit, say, 150 × 100 yards for a battalion of infantry or a brigade division of artillery, with the drill shed either adjoining it, or in immediate proximity to it.

The whole plan should, of course, be arranged with a view to easy approach, simple drainage, general symmetry, and free access of air and sunshine to all occupied buildings, and the spaces between them, with, if possible, ground for recreation and training for the troops, in the immediate neighbourhood.

The possibility of future extension of each part of a barrack, though I mention it last, is a very important consideration, and should never be lost sight of in these days of constant change and progress.

The intervals between buildings is limited to a sanitary minimum in the case of occupied rooms, of twice the height from ground floor to eaves, though this may, of course, be exceeded with advantage where the price of land is not a prime consideration.

Before considering any typical site plan of what a barrack may be or should be, I propose first to describe one or two instances of what a block plan should not be, and for this purpose I have selected first one very well known for its insanitary history, viz., the Royal Barracks, Dublin (*Plate* I.).

Insanitary Block Plans.

These barracks were built about 1700. They consisted of high buildings in closed and partly closed squares, some of the sides of the squares running parallel to each other, so close as to form narrow lanes, to which little air and no sunlight ever obtained access. For many years enteric fever occurred from time to time, culminating in what almost amounted to an epidemic in 1887 and 1888. In the early part of 1889 an exhaustive enquiry on behalf of the War Department was instituted. This enquiry revealed the facts that (1) the drainage, though remedied from time to time, was faulty and leaky; (2), that the water service was leaky, resulting in a certain amount of pollution of the supply; (3), that the buildings were too crowded together for proper circulation of air; (4), that there was a large accumulation of dust between the floors, containing an enormous number of microbes; (5), that owing to the walls being built of two skins and filled in with loose small stones and rubbish, without any mortar to speak of, there was in them an immense accumulation of dust and filth of every description, all charged with microbes. Further, through the holes in the walls in which the joists rested there was free communication between the interior of the walls and the spaces between floors.

As a result of this report, large portions of the buildings were demolished to relieve the congestion. Drains were re-laid, water supply thoroughly overhauled, floors re-made, holes in walls stopped up, ventilation improved, and everything done to bring the barracks, as far as possible, up to modern standard.

Two other instances of old block plans are shown on *Plate* II., viz., that of the Linen Hall Barracks at Dublin and of the Cavalry Barracks at Hulme, Manchester. The first is a good instance of abnormal deficiency of internal freedom of circulation of air, owing to the barracks being too concentrated; although, perhaps, it is only fair to say that this pile of buildings was originally the central linen market of Dublin, and was not designed for occupation. The second is an excellent example of an equally insanitary result from an opposite cause, viz., by crowding the barracks against the outer wall, and subjecting them not only to their own nuisances, which are carefully confined to the narrow strips between the barracks and the wall, but also to those of the crowded streets of a very dirty part of Manchester, which touch the barracks almost all round. The real facts are much worse than they appear on the drawing, owing to the great height of some of the surrounding mills and factories.

Another disadvantage which might not occur to anyone at first sight in building so near the boundary was the liability to damage by the ragamuffins of the town, of which I had some personal experience a few years ago.

A typical site plan for an infantry brigade is given on *Plate* III. Here it will be seen the four battalions are separated from one another by cross roads, and are themselves divided by longitudinal roads into three main portions, viz.:—(*a*), for officers' buildings; (*b*), for single men's barracks and parade; and (*c*), for married soldiers' quarters, a strip being reserved for brigade accessories between the central battalions. Two methods of arranging the buildings to suit varying orientations are indicated on the plate, the relative positions of the blocks in either case conforming generally to the rules above given.

Typical Block Plan.

The particular form of men's barrack block shown in these diagrams is the latest type which has been prepared to meet the public demand for dining-rooms for soldiers, and is described and illustrated later.

Drawings of typical site plans on the above lines for artillery and cavalry are under discussion at the present time.

In the two following plates are shown a couple of examples of modern block plans, adapted more or less from the type just described, to suit particular sites.

The first of these (*Plate* IV.) represents the two new barracks at Colchester called Sobraon and Gujerat. These show two stages in the design of barrack blocks, viz., the single company block type in Sobraon Barracks, and the half battalion combined or verandah type in Gujerat Barracks.

Modern Block Plans.

Both these plans contravene the rules given above in the matter of the view from the guard houses, and also in the small extent of the parades. These defects are due to limitations of available site. The Gujerat, or later plan, shows the officers' mess and commanding officers' quarters in better positions than in the case of Sobraon.

The next instance (*Plate* V.) is an illustration of the Gough and Keane new barracks at the Curragh. Here the site is peculiar, and we have to offend some of the canons already laid down, principally that of aspect. This, however, is not so material in a case of this kind, where the country is open, nor with this new design, in which the barrack blocks are so far apart.

The parade here is long and narrow, owing to exigencies of site, but otherwise the general rules are particularly well complied with.

The arrangement of the band blocks on this plan, it will be noticed, differs from that shown on the typical site plan for the reasons,—

(1), that it has just now been determined to give a whole company block to the band, some of the rooms being used for dining and practising; and (2) that it is considered desirable to provide for the future possible extension of the block into a double company or even a half-battalion one, with its necessary accessories, in case of any increase being made in the strength of infantry battalions—not an impossible contingency after the present war.

There are, of course, several steps in the design of block plans, which want of space will not permit me to detail, between the period represented by these very recent ones and those of the Manchester and Dublin epoch, shown on *Plates* I. and II. Examples of these will be found in the depôt type of barracks built under the Military Forces Localization Act, of which Bury is a good instance, and in the plan of Aldershot, lately re-built. The latest block plan of all is of our proposed camp at Salisbury, but this is, unfortunately, not in a sufficiently advanced stage for reproduction.

(iii.).—Barrack Buildings.

We now come to designs of actual barrack buildings.

Barrack Blocks.

Plate VI. shows two instances of overcrowding in barrack-rooms, to which I alluded previously, viz., at Gibraltar and Guernsey.

In the former case long lines of beds nearly touching one another are arranged on either side of a casemate of great length, lighted and ventilated practically from one end only. In the latter case the beds let down as shewn, cover almost the entire floor space.

A similar instance taken from considerably nearer home, viz., a barrack-room in Brompton Barracks, is shown on *Plate* VII.

In this case the rooms are placed back to back, and consequently get no through ventilation; those in the front on the basement floor also look into a dry area in addition. Both these defects would, of course, be absolutely inadmissible in a modern barrack.

The interval of history between the period of this design and that of the next plate is represented by a progressive series of types, the last of which is exemplified in the barrack blocks at Aldershot and Holywood.

Next in order after these comes the company block type illusrated on *Plate* VIII. This is a double-storeyed block, comprising on each floor two 24-men rooms on the flanks, and in the centre two ablution rooms, one N.C.O.'s room, a company store, and central staircase.

The number 24 is a convenient division for administrative purposes, as representing a section, but gives a room rather difficult to warm uniformly.

This design is the recognized company type at the present time, and if it has defects they may be briefly summed up in saying that we now try and avoid three beds together in a barrack, even more studiously than heretofore, and that unequally spaced windows and windows at ends do not lend themselves either to cubicle construction or extension. The roof also is not quite as simple over the central portion as it might be.

Occasionally, when a site for mounted troops is cramped, we still build men's rooms over stables, not, some will say, a sanitary combination, although on this point opinions are divided.

Such a block was recently designed for new artillery barracks at Woking, but has since been abandoned in favour of a new verandah form of barrack, similar to the half-battalion infantry type shown on *Plate* III., with separate stables.

The new half-battalion combined barrack is shown in detail on *Plates* IX., X., XI., and XII. in plan section and elevation.

The complete element is shown on the key plan on *Plate* IX., and consists of two double-storeyed blocks, each holding two companies, facing inwards towards dining-rooms, and cookhouses built between them, and communicating with them and with each other by means of verandahs and covered ways.

The double-company blocks are arranged in 12-men rooms, with passages between, leading from the verandahs on the inside to ablution rooms on the outside, there being a through communication *viâ* the latter on the ground floor. This, the most recent arrangement of ablution rooms, is considered a distinct sanitary improvement.

The N.C.O.'s, with the company stores and staircases, are located on the inner side of the verandah, opposite the centre of each company.

The urine tub, it will be seen, is still provided; and though admittedly a blot on every design from an æsthetic point of view, it has been proved more sanitary than any form of night urinal short of a disconnected annexe, such as is used in the case of hospitals.

The dining-room block is shown divided into two company dining-rooms, which communicate through company wash-up rooms direct to the serving windows of the cookhouse on either side. This arrangement, while facilitating the rapid and hot service of dinners, also enables the crockery and soldiers' delicacies to be kept outside the dining and barrack-rooms.

The cookhouse is conveniently arranged for the double service, and at either end are provided bath-rooms (four for men and one for N.C.O.'s) and drying-rooms (one per company). The latter, as well as the dining-rooms, are heated from a boiler-room in a basement below, which also supplies the hot water for use in bath-rooms, cookhouse, and wash-ups (*Plate* X.). This plate, and also *Plate* XI., shows the elevations; these have been slightly modified since these drawings were prepared, with a view of reducing everything to the minimum of cost and the maximum of simplicity.

The estimated cost of this half-battalion barrack is, notwithstanding the greater advantages and conveniences, very little more than that of similar accommodation provided separately, as heretofore.

Barracks on this pattern are to be erected at Salisbury, Colchester, Pembroke Dock, and the Curragh.

The windows are a peculiar feature of this design, and are the outcome of a statement made in the House of Commons, by which we are committed to build every new barrack in such a way that will enable it to be converted into a dormitory, with a separate cubicle partitioned off for every individual soldier.

Although experiments with cubicle divisions have actually been ordered to be tried in two barracks, viz., Woking and Dublin, where separate dining-rooms already exist, I will not venture on such controversial ground as to forecast the results as affecting the general introduction of the cubicle system into the army, but I may say that, in point of design, such a step, while adding to the cost of barrack accommodation, would materially increase the difficulties of sanitary construction.

A detail of this special window is given on *Plate* XIII., showing how it is made adaptable for first, a single, and, later, without damaging the brickwork, a double window of greater width, with a cubicle partition abutting against the central mullion.

Married Quarters.

After the *scandalous* period to which I have already referred, the first quarters especially provided for married soldiers consisted of single rooms arranged four on a floor, two on either side of a central gangway and staircase, on two or three floors.

The next concession to decency was the three-roomed type, consisting of living-room, bedroom, and scullery.

Next follow the barrack attic type and the depôt type, in which differences were made in the numbers of rooms and the style of their finish, for allotment according to the *rank* of the occupant. Up to this time domestic conveniences in the shape of W.C.'s were entirely detached from the quarters.

The next step was a verandah type in which these conveniences were arranged at the ends of the blocks, and at the same time the obvious justice was recognized of allotting the different sized quarters according to the number of a soldier's family instead of according to his rank. Careful statistics were taken, and the classes of quarters were eventually reduced to three—"a," "b," and "c," without distinction as to finish or to the rank of occupant.

The "a" quarter has 1 bedroom,
"b" ,, ,, 2 bedrooms,
"c" ,, ,, 3 ,,

besides in all cases a living-room and scullery.

The latest types added to these comforts a separate W.C. to every quarter. These constitute the self-contained attic and self-contained verandah types shown on *Plates* XIV., XV., XVI., and XVII. The titles of these quarters sufficiently indicate the character of their design; their cost is about equal, the expense of the extra staircases in the attic type being balanced by that of the verandahs in the verandah type.

The latest type of all is a modern adaptation of a quarter of the old depôt type, and is illustrated on *Plate* XVIII. The quarters are all alike, and only two-storeyed; they are comfortable working men's quarters without being luxurious, and the design is one among many of present-day barrack designs in which economy, dictated by the ever-growing rise in prices of labour and materials, is sought after at the expense, if necessary, of external appearance.

Each quarter has four rooms (*i.e.*, is a "b" quarter)—living-room, scullery, and two bedrooms, with W.C., and each pair are so arranged that by throwing one bedroom of any one quarter into the next we get a three and a five-roomed quarter, *i.e.*, an "a" and "c" quarter in place of two "b's."

This arrangement will not, of course, give the strict proportion of classes of quarters laid down for a battalion; but it will err on the side of liberality, which is, perhaps, a good thing in the light of modern tendencies, and where sites are not restricted, will be found to give a very acceptable house at a cost which will be not much more than that of other types, notwithstanding the greater area occupied, owing chiefly to the readiness of contractors to take up work similar to what is being undertaken every day in civil life, and also owing to the repetition of the same items in every quarter.

W.O.'s Quarters.

A new design for warrant officers' quarters has also lately been got out as a terrace type, and is shown on *Plate* XIX.

Other Types.

New types have also lately been prepared of almost every building required in the design of barracks, primarily for use at Salisbury, and with a view also to improved planning combined with strict economy.

Although I have been obliged to omit all reference to officers' accommodation and to confine my remarks almost entirely to quarters for N.C.O.'s and men, other barrack buildings have an equal claim on our attention. These include, besides officers' quarters and messes, two large classes of buildings known as regimental and garrison accessories; the former consisting of canteens, recreation establishments, sergeants' messes, laundries, &c.; the latter, which are the natural outcome of the modern tendency to concentrate large bodies of troops in one place, comprising churches, brigade and divisional offices, staff quarters, Engineer and Army Service Corps establishments, garrison schools, etc.

Ventilation.

Intimately connected with the designs of buildings are, of course, the subjects of ventilation, lighting, and warming, and of these we can hardly consider any one in its relation to the soldier's comfort apart from the others. All of them also cover far too much ground for me to attempt to deal with them here in detail.

Briefly, the acme of good ventilation is to replace the air in a room, as it is vitiated by the occupants, by pure air from without, both as rapidly and thoroughly as possible, without causing draughts or changes in temperature; and the sizes and number of ventilators now laid down for barrack and other rooms are based on this principle. The allowance of cubic space per man is consequently a governing factor in this calculation; other considerations, however, especially in winter, have to be taken into account, such as the effect of window surface in cooling the air, and the different effects of different modes of warming and lighting.

To get ventilation thorough, and not confined to the lower portions of rooms, the necessity of keeping windows up as high as possible and of ventilating through ceilings is now made an important feature of this branch of barrack design.

The tendency has been in the immediate past rather to over-ventilate, and in some cases to over-provide military buildings with window space (an instance having occurred of a barrack in Glasgow where it was actually found necessary to block up half the windows). Now, however, the part played by smoke flues *qua* outlets, and leaky doors and windows *qua* inlets, has come to be more recognized, and occupants of Government quarters are saved much trouble in pasting paper over offending ventilators, and the State both time and expense in removing the same.

The flushing of a room with fresh air, just as a drain is flushed with water, is much needed to obtain really efficient ventilation or the maintenance of a high purity standard of air; and the provision of separate dining-rooms will be a great aid in this direction by allowing the windows of the barrack-rooms to be kept open for stated intervals during the day.

The difference between good and imperfect ventilation and the necessity for the former is not always easy to grasp in practice, however much we hear about it in theory; but I think my point about the impurity of barrack-room air about breakfast or dinner-time will appeal to everyone who has ever been an orderly officer in barracks.

As to warming, we are again governed by the *almighty dollar*, and while fireplaces are more cheerful, and heating by pipes and radiators, either with steam or water, more uniform in their effects, we are confined to the employment of one or other system according to the purpose and use of the rooms to be warmed, pipes being more suitable to public rooms and stores, and fires to private rooms. Warming.

Ventilating grates which heat a portion of the fresh air as it enters the room in winter are commonly used in barracks, and there is much to be said in favour of them; but the disadvantage of having a fire on one side or at one end of a room only, cannot be overlooked, and a central fireplace would obviously be a great improvement if we could get over the difficulty of the down-draught flue; a difficulty which, unless we are to have a great, unsightly stove pipe running up the heart of every barrack, is one which has to be overcome. Much has been done to meet this difficulty by various stove makers, and with some success, which when established will bring us as near as it is possible to get to the much desired uniform warming and cheerfulness combined, which we cannot get at present without the prohibitive expense of the double system of pipes *and* fires.

This costly combination is, I believe, actually adopted in private houses in climates like that of Eastern Canada, where the cold in winter is extreme.

Lighting.

Lighting is another large, and I may say growing, subject at the present time, and one which affects, of course, both the warmth and purity of the air in any room. Ordinary gas with ordinary burners, a system hitherto almost universally employed, at any rate at home stations, must ere long give way to the improved forms of lighting which are now coming to the front, *e.g.*, electricity, acetylene, and incandescent gas at high and low pressures.

Electricity has, of course, many advantages over all the other systems, but is expensive both to instal, to meter, and to maintain; but as it is being more used it is, of course, becoming cheaper, and is being installed now for large new hospitals, such as Millbank, and large barracks, as Aldershot; also at Halifax, Nova Scotia, and other places.

Acetylene has, I feel sure, a great future before it, but as a lighting agent is at present in its infancy, and is far too dangerous a plaything for experiment in barracks.

Incandescent systems are distinctly economical, but are too delicate in their present stages, and too expensive to maintain where the soldier is concerned; these delicacies are gradually, however, being overcome by new inventions; and for external lighting under high pressure these systems leave very little to be desired, although they have not yet found much favour for military purposes. The use of a suitable incandescent system would possibly solve a very difficult question now under discussion, viz., the necessity of giving soldiers better light in barracks without further burdening the estimates.

(iv.).—Hospital Buildings.

The special study of hospital construction is a large and most interesting branch of modern military designing, and has already been made the subject of an S.M.E. lecture by the late Sir Douglas Galton. All, therefore, I propose to do is to describe a small hospital such as is shown on *Plates* XX., XXI., XXII., and XXIII., and indicate the principal points which govern the composition of the design.

The number of beds to be provided is generally calculated as a proportion of the garrison, which in England amounts to $5\frac{3}{4}$ p.c., and these numbers are again divided into different classes of beds and wards, in accordance with a recognized table of percentages.

The next step is to determine the block plan of the hospital. *Plate* XX. indicates how this may be arranged by the division of the principal buildings into pavilions containing in the centre the administration items, and on the flanks the actual wards. In one corner is the isolation ward, 40 feet from any building and public road, and protected by a double fence to prevent contact between convalescents from the main and isolation wards. On this fence is also provided a disinfector, with its receiving door inside the isolation enclosure, and its issuing door outside the same.

The mortuary and foul linen store are here shown near, although not in connection with the isolation hospital—the governing condition in the case of a mortuary site being that it should be on a road, so approached that, if possible, funerals may not have to pass in front of the hospital or neighbouring barracks.

To one side are placed barracks and quarters for single and married orderlies, not too near each other, not too far away from the hospital.

Turning to *Plates* XXI. and XXII. it will be seen that the ward blocks, which are oriented as nearly north and south as the site will allow, are divided by a lateral corridor into two parts, the smaller parts being confined to what may be termed the objectionable items, such as lunatics, prisoners, itch cases, etc. ; the large to the ordinary and special case wards, main staircases and lifts. The orderly's rooms and sculleries attached to the main wards serve also a special case ward in each case; the orderly's room being made just large enough to be used as a single bed ward in case of pressure. In the case of the small wards on the far side of the corridors separate sculleries are dispensed with, the entrance lobby being made to answer this purpose.

The lunatic ward, which is kept on the ground floor, is approached direct from the lobby, and not through an orderly's room, as was heretofore considered necessary. The prisoners come on the first floor over the lunatic ward. In the other pavilion the itch ward is kept on the ground floor, to avoid possible contact on the stairs, and a separate outside entrance is provided.

Over this ward is arranged the operating room, a necessary adjunct of every important hospital. Its essentials are that it should be top lighted, and should lend itself to the easy conveyance of patients to and from it; it should also be near some small ward, where chloroform can be administered. In the present case the single bed ward would serve this purpose, it being handy to the lift and near the operating room. In the case of a detached operating theatre a special anæsthetic room has to be provided. A lavatory, sink, and a few glass shelves complete the requirements of an operating room, so far as the Engineers are concerned.

Each principal ward has its W.C. and lavatory annexes either separate or combined, and detached from the main building by a narrow ventilated lobby.

The central block, or pavilion, is divided on the ground floor into administration, stores, and kitchen portions. The administration portion consists of a consulting-room, dispensary, and waiting-rooms, arranged with a view to greatest convenience in the examination of patients, and providing them with medicine. Two waiting-rooms, *i.e.*, for men and women, are provided here, and are often necessary in the case of small hospitals, where no medical inspection rooms exist in barracks. A small cupboard under the stairs is provided for drugs, in place of a store, such as would be necessary in a large hospital—and W.C. conveniences are also shown for use in case of need.

On the other side of the cross corridor are arranged the hospital stores, the sizes of which are fixed by the number of beds in the hospital.

Separated from these again by another passage are the cooking arrangements, including kitchen, scullery, larder, and outhouses. Here the larder takes the place of separate bread, meat, and milk stores, which in temperate climates generally find a place in large hospitals. A cook's room is not considered necessary in this case, owing to the small size of the hospital and proximity of the barracks.

On the first floor of the central block a day-room and dining-room for the use of patients are shown, with a good outlook. Behind these is arranged the medical officer's room, with a lavatory and W.C. in the vicinity.

Over the stores is the steward's quarter, and lift for the service of food.

Plate XXIII. shows how the isolation block is arranged in the simplest and most economical way for the separate treatment of two kinds of infectious diseases in one building.

I have not been able to illustrate an example of a thoroughly bad hospital; and although such examples do exist, many have been altered and improved to meet the most important of modern requirements. I recollect a case, however, where, if I remember rightly, one miscellaneous block had a kitchen between an itch ward and a dead-house, with a married quarter next the itch ward on the other side, and some stables in the same block!

(v.).—Details.

I propose next to deal with one or two familiar details, in which recent custom has introduced some improvements. Floors.

The first of these deals with floors (*Plate* XXIV.). Here is shown a section of an ordinary simple floor, carried by deep wood joists resting on a plate supported on a corbel course, the floor itself being of the grooved and tongued pattern.

The disadvantages of this system of flooring are—

(*a*). That the floor boards are difficult to take up and repair.

(*b*). That the joists are expensive, and make the floor exceptionally elastic.

(*c*). That the method of supporting on a corbel course tends to throw a strain on the inner skin of the wall.

This disadvantage can be obviated by—

(*a*). Adopting a rebated floor.

(*b*). Making use of steel binding joists, and so reducing the bearing and depth of the wooden joists.

(*c*). By building the ends of the joists into pockets in the wall; a continuous iron bar being inserted to provide a suitable bed, by which the load is distributed evenly, and a space left all round the ends of the joists to avoid contact with the wall, and the attendant evils of dry rot, and consequent liability to failure.

It was this liability that was responsible for the introduction of the adoption of the corbel system; but the "building in" system is acknowledged by experts to be the best of many, and really requires no more supervision than the proper and safe building of the "corbels."

The other details of construction I have selected for illustration are those which, if not properly supervised, constitute a great risk of fire by the improper proximity of woodwork to smoke flues. Recent cases have occurred of fires due to this cause, and rules for guidance in this important matter have been prepared and issued in the form of a circular. These are given below, and are illustrated on *Plate* XXV. Woodwork Near Flues.

Rules governing Proximity of Woodwork to Fireplaces and Flues.

(1). Sides and divisions of smoke stacks may be of 4½-inch brickwork, other conditions permitting.

(2). The back of every fireplace opening in a party wall should be at least 9 inches thick from the hearth to 12 inches above the mantel.

(3). Woodwork should not be placed under any chimney opening within 10 inches from the upper surface of the hearth of such chimney opening.

(4). Every soot door should be at least 15 inches from any woodwork.

(5). No woodwork shall be built *into* any wall or chimney breast nearer than 12 inches to the inside of any flue or chimney opening.

(6). Woodwork shall not be placed in *contact* with the brickwork or stonework about any chimney or flue where the substance of such brickwork or stonework is less than 9 inches in thickness.

(7). When a less thickness is unavoidable either the brickwork or stonework must be rendered, or the woodwork kept, 2 inches away from it.

(8). Wood plugs should not be driven nearer than 6 inches to the inside of any flue or chimney opening, nor any iron holdfast or fastening nearer than 2 inches thereto. This precaution is especially necessary in the case of skirtings running along back of fireplaces or flues in adjoining apartments.

(vi.).—External Treatment.

A final word on external treatment.

Modern Conditions.

Able lectures on this subject have already been delivered at the S.M.E., and far be it from me to criticise what has been said on this subject. I may safely say, however, that the conditions of barrack architecture to-day are somewhat as follows :—

(*a*). Military architecture as a separate school has been killed by the natural developments of the art of fortification to keep pace with modern weapons; and the days of moated castles, with keeps and frowning battlements, are over, never to come to life again.

(*b*). Architecture generally is to-day no longer tied by the strict codes and conventions of the various periods as it was a century ago or less, and we have consequently a far freer hand with which to treat military buildings than of old.

(*c*). This liberty of action as regards period is coupled, nevertheless, with the impediment that a restricted finance places in our way, and the only treatments at our disposal are in consequence those of great simplicity; so that in endeavouring to convey through the exteriors of buildings an impression of their relative importance or special uses, we are obliged to rely more upon variations of form than upon a sliding scale of ornament.

It may be said that a perfectly simple treatment cannot be architecturally artistic or correct; but, nevertheless, a plain elevation in skilful hands may be made very much more pleasing in effect than a more elaborate one drawn without knowledge of architectural detail, or without artistic feeling.

(*d*). The scattered disposition of barrack buildings, and their varied character, adds further difficulties in the attainment of any effects of symmetry or mass.

These conditions lead us to adopt the free styles of the late Tudor and modern Renaissance schools, with occasionally a Gothic treatment.

Of the latter, the Portsmouth Barracks are a good, but not a cheap, example. Of the Renaissance style, Hyde Park Barracks and Grangegorman Barracks, Dublin, are emblematical, whilst abroad we have excellent specimens of Italian style at Malta. None of these can be said to be quite typical instances of barrack designs, however, owing, in the case of the two former, to their prominent situations, which serve as an excuse for unusual expenditure, and in the case of Malta, to the cheapness of labour and a plentiful supply of easily worked stone. Examples.

Materials, of course, also affect designs to a considerable extent.

Again, special surroundings and archæological interests sometimes govern the external treatment of barrack buildings, such as that of the new recreation establishment now being built at the Tower. Here was a case where we were subjected to the fire of very severe provincial criticism in a newspaper paragraph, which was copied into many of the London dailies. Fortunately, the criticism was as unsound as it was abusive.

The new building being within the enceinte of the old Tower Fortress is, according to mediæval precedent, treated in a secular and domestic manner, and to take it out of competition with the old grey stonework, as exemplified by the great White Tower which overlooks it, it has been constructed with special thin red bricks, and with stone dressings and red-tiled roofs, the details being of the time of Henry VIII., who made additions to the interior of the Tower.

Another interesting exterior is that of the new barracks at Winchester. The original building was designed by Sir Christopher Wren as a Royal Palace for Charles II., and occupied the site of a moated Norman castle, of which one fragment only remains.

The palace, however, was never tenanted by the king, and in the reign of George III. it was altered, another storey added, and otherwise adapted for use as a barrack for troops, accommodation being found for about 800 men.

The palace (a characteristic Renaissance structure) was built in the form of three sides of a square. It occupied a fine situation on the side of a hill overlooking the city of Winchester, the hollow of the square facing east and opposite the west end of the cathedral about a quarter of a mile away (evidently a feature of the original design).

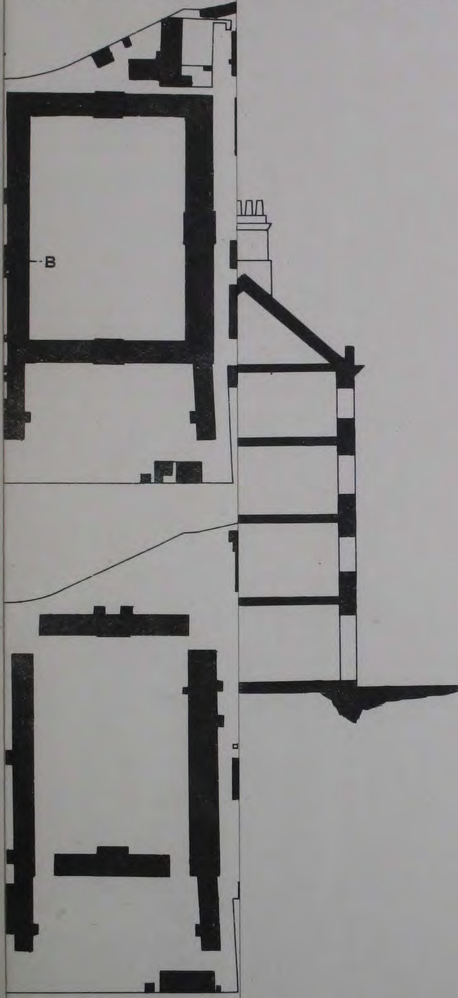
The old Norman moat was filled up with the *débris* from the S.W. Railway cutting which skirts the western boundary of the War Department property.

In 1894 the building was totally destroyed by fire. Fortunately, however, a large proportion of the Portland stone dressings, including some finely carved capitals, remained fit for re-use; and the barracks now being built on the site are specially designed with a view to working in the old stonework, although, of course, the modern requirements necessitate a totally different plan from that of the original building.

In conclusion, I wish to tender my best thanks and acknowledgments to those officers and members of the S.M.E. and War Office Staffs who have kindly assisted me in the compilation of this paper.

ROYAL BARRA

PLATE I.



PAPER III.

SIEGE OF KIMBERLEY.

REPORT OF ROYAL ENGINEERS.

(1). The original report by Lieut. MacInnes as to the proposed defences of Kimberley is attached to this report. In the main these proposals were adhered to, though additional works were built, and by the inclusion of Beaconsfield, and subsequently Kenilworth, the line was much extended. Retrenchments were not employed except on the sides most threatened by the enemy. The De Beers Consolidated Mines, Limited, gave every assistance in the company's power. Labour and materials were throughout the siege put at the disposal of the R.E. officers. This assistance was most valuable, as on account of the large area the works covered it was impossible for the small party of Engineers available to carry out the work alone.

(2). The order to begin work was given on September 25th, one section of the 7th (Field) Company, R.E., under Lieut. McClintock, having arrived on September 21st. The more important parts of the defence were put in hand at once. The execution of the work was as follows:—

Commenced.	Work.	Completed.
25th September ...	Rinderpest Redoubt	3rd October.
	Stables Redoubt	7th October.
	Reservoir Defences	13th October.
	Camp Redoubt	10th October.
	Sanatorium House and Breastworks...	7th October.
26th September ...	Old and New Kimberley Redoubt ..	7th October.
27th September ...	Kenilworth Redoubt	17th October.
	Smith's Redoubt	10th October.
	Schmidt's Drift Redoubt	13th October.
	De Beers' Redoubt	30th October.
28th September ...	Civil Service Redoubt	10th October.
4th October	Belgravia Redoubts	10th October.
10th October ...	Transvaal Rd. Breastworks...	17th October.
18th October ...	No. 1 Searchlight	6th November.
28th November ...	No. 2 De Beers	
4th January... ...	Otto's Kopje...	10th January.
15th January ...	St. Augustine's	27th January.

The other minor works of the defence, including obstacles, were carried out as opportunity offered, either concurrently or subsequently. Mines were also laid. A large quantity of mimosa bush was cut down outside the line of defences with the double object of clearing the front and supplying material for abattis. Some demolitions had also to be carried out. These included half of No. 1 Location, the whole of No. 4 Location, three private houses near Schmidt's Drift Road, and some fences in the west end and in No. 3 Location. Owing to frequent alarmist rumours as to a projected attack by the enemy, the work was pushed on as fast as possible. This entailed additional expense, as the small staff of Royal Engineers were unable to superintend all the work going on. The main works were all in a defensible state by the 8th October.

(3). Labour Available.

The work was carried out under the superintendence of the 45 N.C.O.'s and sappers of No. 1 Section, 7th (Field) Company, R.E., which arrived 21st September.

The working parties were at different times :—

(*a*). Infantry working parties of 1st L.N.L. Regiment.
(*b*). Compound natives supplied by De Beers.
(*c*). Native labour supplied by contractors.
(*d*). Convict labour—natives.
(*e*). Relief work boys.

(*a*). Infantry working parties were used to build only one work, *i.e.*, Camp Redoubt, and to clear the ground in front and form an abattis round this work. It was not practicable to supply this form of labour more extensively, as, owing to the small number of regular infantry (half a battalion) available and the very extended nature of the defence, it was not considered advisable to take them away from their posts. In the early part of the siege they were fully employed at night on patrol duties.

(*b*). The De Beers Company was able in the earlier part of the siege to supply large numbers of natives from the mines under their own overseers.

This, though the best available, was not an entirely satisfactory type of labour on account of the innate indolence and stupidity of the black, and the difficulty the Sappers had in getting them or their overseers to understand what was wanted. Consequently, although accustomed to the use of pick and shovel, the maximum of work was never got out of them. Further, being compound boys, when taken out of De Beers enclosure they were found difficult of discipline.

Later in the siege, owing to scarcity of food, De Beers turned the greater part of their natives out to go to their homes, so this kind of labour then ceased to be available, and (*c*), (*d*), and (*e*) were resorted to.

(*c*). *Contract.*—Certain portions of the work were executed by natives under contractors.

This form of labour was perhaps the most satisfactory, as, the contractor having a very much greater hold over his men, and also the native being of a better class, a very much higher percentage of work was done in the same time.

(*d*). *Convict.*—Small portions of work—chiefly on the mounted camp—were executed by native convicts. This was a most unsatisfactory form of labour, as the convicts did as little as they could, and had to work under armed escort.

(*e*). *Relief Work Natives.*—Late in the siege, January, 1900, De Beers natives being no longer obtainable, relief work natives were employed on works, partly to assist in employing these natives. This labour was not very good, as the natives were underfed at the time and unable to perform a fair day's work. However, it was the best labour obtainable, and fulfilled one of its objects in giving employment to the natives.

(4). Material Available.

The chief materials required in the defence were :—

(*a*). For revetting.
(*b*). For blindages.
(*c*). For head cover.
(*d*). For mines.
(*e*). For obstacles.
(*f*). For shelters and latrines.
(*g*). For tools.

(*a*). Revetting.—For this purpose were used :—

(i.). *Old Mine Trucks.*—This made a very good and permanent revetment when carefully placed ; however, a good deal of time and trouble was necessary to place them.

(ii.). *Mud Bricks.*—A large quantity of these became available, notably for the Transvaal Road Works, by pulling down the native location there. This made a very good and permanent revetment, especially when the crevices were subsequently stopped with mud.

(iii.). *Tramway Sleepers (Wood).*—For revetting the Sanatorium breastworks. A quantity of these were borrowed from the depôt of the tram line, which was close at hand. An excellent revetment in every way.

(iv.). *Sacks.*—A very large quantity of sacks were consumed for this purpose, especially in the case of the works on the softer tailing-heaps, and where works had to be quickly made defensible under fire and subsequently improved. This was not a very satisfactory form of revetment, as the sacks rapidly rotted, and had to be replaced.

(v.). *Galvanized Iron.*—Certain breastworks were revetted with corrugated iron sheets, held back by iron stakes and anchorages. A good form of revetment where the ground is not rocky.

(*b*). BLINDAGES.—Constructed out of squared timber and galvanized iron supplied by De Beers. This expensive form was necessary, as there is no native rough wood available.

(*c*). HEAD COVER.—Sacks supplied by De Beers and local dealers; also 1,000 tarred bags brought up by R.E. for defence of Modder River.

(*d*). MINES.—The dynamite, leads, and batteries were supplied by De Beers. Dynamite was alone used, the small quantity of powder available being required for shells, etc.

(*e*). OBSTACLES.—It was necessary to surround the defence with an efficient obstacle to compensate for the paucity of the garrison and to prevent a rush at night between the works. Accordingly a barbed wire fence was run around almost the whole of the 11½ miles of the main defence. Where practicable this was strengthened by a stiff abattis of mimosa bush, cut down to clear the front. Large amounts of wire fence and abattis were also constructed round Beaconsfield and Kenilworth. Where there were no bushes the fence was increased in height and strength. Iron poles were necessary on account of the rocky nature of the ground. These were made at De Beers forge by pointing the ends of old pieces of iron pipe or rail. The wire (with the exception of a small quantity in charge of R.E. for defence of Modder River) was obtained from De Beers. A very large quantity was used.

(*f*). SHELTERS AND LATRINES.—As very few tents were available for the garrisons of the numerous redoubts, breastworks, and barrier posts in the very extended defence, shelters had to be built at each point. These were constructed out of wood, with canvas sides and galvanized iron roofs. Had the eventual duration of the siege been in the least anticipated, they would have been more solidly constructed; as it was, after a couple of months' use, they required constant repairs. Latrines were constructed at each post out of galvanized iron or canvas and wood.

(*g*). TOOLS.—The De Beers Company were able to lend us as many picks and shovels as were necessary, also axes and wheelbarrows. The R.E. section had a certain supply also.

(5). SEARCHLIGHTS.

At the commencement of the siege De Beers was in possession of several searchlights and complete plant, these being used to prevent thefts at night from the "floors." The projectors and reflectors were of the usual service pattern, *i.e.*, Schuckert projectors, with automatic lamp and parabolic reflectors. At the beginning of the siege three of these were put in use, one being mounted at Premier 9th October, one at Rinderpest Redoubt (same date), and one at No. 1 Searchlight (already in position). These ran at 60 volts and 60 ampères. Subsequently two Mangin projectors with hand lamps were mounted, one at No. 2 De Beers and the other at the Reservoir, on 8th November. These were not very satisfactory.

Later in the siege the Schuckert and Mangin at the Rinderpest Redoubt and Reservoir were exchanged, as the latter place became of more importance in the defence.

The operators were R.E. and De Beers' men; the latter, being accustomed to run these lights in peace time, proved very useful.

(6). MINES.

Land mines were very extensively employed in the defence, especially where there was any dead ground which could not be searched by fire from our works.

These were entirely "Observation Mines," the electro-contact or mechanical systems being too dangerous for employment on account of the number of natives who were always about. These mines varied in size from 5lbs. in ordinary cases to lines of about 30lbs. in the case of buildings which it was undesirable to pull down, but which might afford the attackers cover close to our works.

Dynamite was used in all cases.

Both firing batteries of Leclanché cells and dynamo exploders, of Toflin and Rand pattern, were used; also the current from the electric arc light circuit. The leads were insulated in most cases, lead of size of C7 supplied by De Beers and laid in pipes. However, when this ran out, air line of copper or iron wire was employed, buried leads being used for the last 100 yards or so. The air line was run a few inches above the ground, and concealed as far as possible. The I.R. and C.R. were tested periodically. In some cases "dummy mines" were laid with some publicity in places where "live" mines would have been undesirable. The presence of these mines—live and dummy—is admitted by the Boers to have exercised a great restraining moral effect on them.

(7). Water Supply.

The original water supply of Kimberley was pumped from Riverton (Vaal River) to an intermediate station about 10,000 yards from Kimberley, and thence to the Kimberley Reservoir.

On the 16th October the enemy cut the main close to the intermediate, and the supply ceased. Arrangements were at once made with De Beers to pump the water from the Wesselton Mine direct into the waterworks reservoir. However, as only a limited supply could be pumped from Wesselton, the consumption was limited to two hours per diem, and even then demand (and consumption) exceeded supply.

The mains from Wesselton to the waterworks were already in position, but as the line of main ran a short distance outside our defence, and as a shell might at any moment stop the supply by damaging the pumping engine, a committee was appointed to enquire into well supply. This would have been adequate in case of emergency, but was never required.

Early in the investment it was seen that the possession of Riverton would give the Boers adequate water supply at the intermediate for a force of any size; two attempts were made to cut it at Riverton, but in neither case was the force of mounted infantry and R.E. sent out able to reach the objective.

(8). Cattle Guard Works.

In addition to main defence of Kimberley and the two subsidiary defences of (1) Beaconsfield and (2) Kenilworth, it was found necessary to throw out small breastworks about 1,500 yards to the front in different directions. These are shown in blue on the defence plan, and were intended to give cover to the guard of mounted infantry which daily escorted the cattle to the grazing grounds outside the main line of defence in case of attack. The ground in front of these was cleared of bush and other cover as far as possible. The work was done by natives under R.E. superintendence – the working party at the time being covered by an escort of mounted infantry. The work had very often to be carried out under artillery and long range infantry fire.

On the Reservoir side these works had to be chiefly built out of sacks of earth, as the ground is practically all rock.

(9). Telephones.

Every redoubt and post was connected with a central exchange, so any post could call up and talk to any other. The conning tower had also three wires running to the exchange to allow the O.C. to communicate his orders without delay. There being two systems of telephones in Kimberley, the P.O. and De Beers, these had to be connected with three wires. In this way any inconvenience due to having two exchanges was overcome.

(10). The Garrison.

The garrison of Kimberley consisted at first of:

Imperial Forces.

R.A.—23rd Company, R.G.A., with 6 2·5-inch guns.
R.E.—1 section 7th (Field) Company, R.E.
1st L.N. Lancashire Regiment, half battalion, and 1 section M.I. Company.

Colonial Forces.

Diamond Field Artillery, 1 battalion, 6 2·5-inch guns.
Kimberley Regiment, unmounted, 350 men.
" " mounted, 150 men.
Maxim Battalion (De Beers), 6 Maxims.
Town Guard, 2,500 men.

The original idea of the defence was that the works should be occupied by the local corps, consisting of the Town Guard and

Kimberley Regiment, while the half battalion Lancashire Regiment was to be kept as a central reserve.

The guns and Maxims were also to be kept in reserve, positions having been made for them at various points of the defence to be occupied in case of attack.

This idea was, in the main, kept to, but it was soon found that the D.F.H. and one company of cyclists were quite insufficient to do the patrolling and scouting. A local irregular mounted corps, 350 strong, called the Kimberley Light Horse, was therefore raised, and in addition to this corps, the various garrisons of Cape Police along the frontier early evacuated their posts and found their way to Kimberley.

These increased the garrison of Kimberley by 350 men, 3 Maxims, and 2 7-pounder guns. The whole mounted force in Kimberley was thus raised to 800 men with 3 galloping Maxims, and by its mobility formed a valuable offensive force. By its bold use in the early part of the siege the enemy obtained an exaggerated idea of the fighting strength of the garrison, and in all probability, therefore, gave up all idea of being able to attack Kimberley with success.

The distribution of the Town Guard in the defence works is shown in diagram attached to the report. The redoubts were designed for a minimum garrison of 50 men, and the diagram will show that the garrison was distributed accordingly.*

The main defence was divided into six sections, with the Beaconsfield and subsequently the Kenilworth forces distinct. In this way the men and officers, who had practically no military training, obtained a thorough knowledge of their sections, and were able to organize a more effective system of sentries and patrols.

Each man was told off to his own position in the work to which he belonged, and was drilled to use his rifle at that position. In addition to this, the men were instructed by N.C.O.'s of the Lancashire Regiment and Kimberley Regiment in simple drill movements, and very soon became efficient in these.

On occasions when called upon to act against the enemy beyond the line of defences the men showed great keenness, and acquitted themselves most creditably.

(11). General Aspect of Siege from R.E. Point of View.

1. The siege of Kimberley presented several unusual characteristics, in that one of the chief objects of the defence was the

* Diagram not received.—[Ed., *R.E.P.P.*].

protection of the various mines and their valuable machinery. So, as these mines were extended over a very wide area round the town, the line of defence was necessarily extended out of all proportion to the available garrison.

Further, as each mining area contained one or more large *débris* heaps—varying from 40 feet to 120 feet high—and as these were all commanding points within close artillery range of the town, and were practically the only high ground in the vicinity, it became necessary to occupy them all, even at the risk of too great extension.

2. The defence was still further handicapped, as, owing to the pacific policy of the Cape Government, nothing of the nature of defence works was allowed to be undertaken till the actual outbreak of hostilities, beyond drawing up plans and arranging, as far as possible, for the distribution of materials.

3. However, by dint of great exertions, the majority of the more important works were in a defensible state by date of first alarm—11th October—and after this date were permanently occupied by their garrisons and completed as rapidly as possible.

4. While the main defence of Kimberley was in progress, the defences of the suburb of Beaconsfield were being organized by Major Fraser (late 1st L.N.L. Regiment), these being originally only intended to hold the enemy in check, in case of an attack on this side, long enough to enable the inhabitants to retreat into Kimberley.

5. About the middle of November it became apparent that the enemy did not possibly intend pushing the attack home; at the same time it became necessary to find grazing ground for the herds of cattle forming the food supply of the town. Accordingly, the already too extended line was further advanced to include Kenilworth and cover the grazing ground between Kenilworth and Felsted.

6. The two sides of the enceinte threatened by the enemy were the north (Kenilworth) and the west (Reservoir to Kimberley Redoubts).

During November the enemy had taken cover and entrenched himself in a dense clump of bush, several hundred yards long, about 2,000 yards in front of No. 2 De Beers. Kenilworth was then occupied (see par. 5), and after numerous skirmishes we succeeded in gaining possession of this advanced post of theirs, cutting down the bush and filling up the trenches. A searchlight was mounted on No. 2 De Beers. A few advanced earthworks were constructed about 1,500 yards in front of No. 2 De Beers for the cattle guard, and the enemy then temporarily transferred their attention to the western side.

7. The western side (Boer positions—Carter's Ridge) was the scene of the most severe engagements between ourselves and the Boers; on 25th November we carried their entrenched positions, and but for the arrival of reinforcements would have captured their laager.

On 27th, while attempting to act in conjunction with the relieving column, we again attacked the same position, but met with such severe resistance that the attack had to be abandoned with considerable loss.

The effect of these two attacks was to cause the enemy to evacuate Carter's Ridge and keep at a respectful distance; but on January 7th, after the Battles of Magersfontein and Tugela, they again occupied the ridge in much greater force than before. They also showed far greater activity at night, both in patrolling and in further entrenching themselves. They also commenced sniping at our patrols and cattle guards daily. Owing to these new entrenchments, and to the information received that the nine 15-pounders captured at Tugela were to be brought against us, the O.C. ordered all works on western side to be strengthened. This was accordingly done; extra blindages were added to existing works, and additional works and shelter trenches thrown up in the intervals. A more advanced position was also taken up among broken ground in front of No. 1 Kimberley in order to offer several successive lines of entrenchments to a possible assault. Otto's Kopje was also occupied to act as an advanced post of observation, and to strike a blow if possible at their communications, and to bring flanking fire to bear in case of an attack.

8. As regards the Boer artillery fire, during the earlier part of the siege (6th November—6th February) only 9 field guns up to 12-pounders were in use. Employed as it was mainly by single guns and at excessive ranges, it had no effect at all on the works. Hits were seldom obtained (most of the fire being directed on the town), and even direct hits did practically no damage, the maximum penetration being about three feet in case of common shell.

Owing to the large amount of splinter-proof cover provided in each work liable to artillery fire, and also to the sharp look-out kept by the garrisons, no damage was done by their shrapnel fire in the few cases where they ventured close enough to use it. Their percuss on fuzes appeared to be very quick acting, as occasional blind shells penetrated considerably further into earth than those which burst. However, on 7th February, the enemy unmasked a 6-inch B.L. gun, throwing 100-lb. shell, at Kamfersdam. Practically no shells were fired at the works, and no hits were reported. The fire of this gun was almost entirely directed on the town, and did a good deal of damage, several houses being set on fire and others considerably damaged. Both common and shrapnel (usually percussion) were employed, and several people were killed and wounded. The houses in Kimberley, being chiefly constructed of galvanized iron and wood, offered no, or at any rate little, protection from this bombardment; on the contrary, they were admirably adapted to burst any shell that might hit them, and give the splinters full effect. None of these houses having cellars (the subsoil being rock), most of the inhabitants built themselves bombproofs out of sacks of earth, etc. Besides these, large casemates were constructed for the women and children behind the various *débris* heaps, and a considerable number of the inhabitants took refuge in the mines.

9. Shortly before the relief the enemy, owing to a false alarm, evacuated Alexandersfontein, and we occupied it. Being an important point on one of their lines of communication and one of their best sources of water supply, the O.C., knowing that important movements on the part of the relief force were pending, determined to hold the place. The enemy brought 2 guns against the holding force and a warm cross rifle fire. The section R.E., with some infantry, had to throw up shelter trenches under this fire throughout the 14th and 15th February.

With reference to the value of the defences against attack, it is stated by the enemy themselves that the mines and searchlights restrained them from attempting an assault, so no idea can be gained of the value of the defence works and obstacles to an infantry attack. It cannot, however, be doubted that these works, standing as the great majority do on tailing heaps 40 to 80 feet above the surrounding country, and interconnected by barbed wire and thorn abattis, would have proved a very serious obstacle to assaulting infantry, at least, if we can judge from our own experiences in attacking much less formidable works held by the Boers round Kimberley.

10. *Practical Value of the Searchlights.*—It cannot be doubted that the numerous searchlights around Kimberley were a great protec-

tion, even if they did not (as is very probable) prevent an assault by night, as they prevented the enemy's patrols coming close enough in to examine our obstacles and other defences. The general situation of Kimberley is especially favourable to the fullest employment of searchlights, as the surrounding country is flat and open, while the lights themselves were mounted on headgears of tailing heaps from 40 to 200 feet above the surrounding plain. At the same time, even under these most favourable circumstances, experience shows that an observer behind the light cannot see even large bodies further than 2,000 yards, except in the case of mounted troops, which are easily seen by the reflection of the light from the horses' eyes.

The moral effect of a searchlight on a man unused to it is very considerable, as when in the light of the beam he is quite convinced that his every movement is watched, while as a matter of fact he is most probably quite invisible to the enemy or operator.

It may be remarked that out of the three towns besieged Kimberley was the only one on which no assault was delivered. This was probably due in part to the searchlights, as Mafeking and Ladysmith both had employed mines, and had not the handicap of the enormous extension of the Kimberley defences combined with a totally inadequate garrison. In support of this view it may be mentioned that the enemy came down very close to Kenilworth at night until a light was mounted on No. 2 De Beers, after which they cleared off.

(12). The original camp for the troops who arrived on 21st September—

23rd Company, R.G.A.
No. 1 Section, 7th (Field) Company, R.E.
4 companies 1st L.N.L. Regiment—

was inside the Reservoir enclosure.

However, owing to the representations of the Medical Officer of Health, it was shifted on the 23rd to the veldt near Newton Home. Latrines were built and water laid on from the Kimberley Waterworks main, which passed close at hand.

On 4th October the Diamond Fields Artillery and the Kimberley Regiment were called out, and joined the camp. Latrines and water supply were similarly arranged.

On 11th October the various works were occupied by the units of regulars, volunteers, and Town Guard told off to them. Shelters, latrines, and water supply were arranged at each work.

On 12th October the reserve of regulars and volunteers was moved to a central position at the Botanical Gardens. The latrines were shifted, and water supply again arranged.

On 17th October a camp was formed close to De Beers' workshops for the mounted troops; mangers and troughs were provided for the horses, and latrines and water supply for the men.

On 26th December the Royal Artillery and Diamond Fields Artillery were moved to a different site.

Owing to the fact that on the 16th October the enemy cut the main of the Vaal River water supply, it became necessary to economize water. It was accordingly turned on for two hours per diem. Consequently, to provide the troops with water for the rest of the twenty-four hours, tanks had to be built at each camp and filled each morning. De Beers were able to supply a number of 400-gallon oil drums, which were extensively used for this purpose.

By order of the medical officer all water for drinking purposes had to be boiled. Utensils for doing this were made by cleansing out and putting handles on old 10-gallon oil drums. Tanks were in some cases supplied for storage of drinking water.

Shelters of wood and canvas were provided to supply deficiency of tents (see (4) (*f*), page 73) at most of the redoubts.

(13). Armoured Trains.

In all there were three engines and four trucks armoured. This was done at the De Beers workshops. Of these, two engines and two trucks were built for Mafeking and sent there, but were destroyed by the enemy near Kraaipan while escorting some guns at the commencement of the war. The other engine and two trucks were built by order of the Officer Commanding in December. In addition to this an engine and two trucks were sent up from Salt River, and were used throughout the siege, and though several times under both rifle and shell fire were never damaged, and were found most useful in drawing off the enemy where sorties were made by leading them in other directions.

(14). Station Enlarged.

Early in December, when the relief of Kimberley was expected, and there was a prospect of a large body of troops having to be entrained and detrained, extra sidings were constructed, and the entrance to the station from the south improved by the points being altered from meeting to trailing points. When the relief actually did take place these additions and alterations proved of the greatest value.

Immediately Kimberley was relieved working parties were organized for the repair of the railway to the south, and in this way over half the distance between Kimberley and Modder River was overhauled and repaired from Kimberley. Telegraph parties also took the telegraph lines in hand.

(15). Cold Storage.

Towards the end of December, the veldt having been practically eaten off, it became a problem how to keep meat for the inhabitants. In order to allow of as many cattle as possible being killed off, the Officer Commanding ordered the De Beers Company to put in hand a cold storage house for 300 head. This was put in hand at once, and completed within a fortnight. It worked most satisfactorily, though ashes had to be used for packing in place of sawdust.

(16). 28-lb. Gun and Shells.

Another item of interest from an engineering point of view was the construction of a 4·1-inch gun, firing a 28-lb. shell. This was made under the superintendence of Mr. Labram, chief engineer to the De Beers Company. This took only a fortnight to make, though the machinery for rifling had to be made in addition, and the gun proved a most effective and accurate weapon, though some difficulty was experienced with the obturator bolt, for which there was no steel sufficiently tough.

It is deeply to be regretted that Mr. Labram was killed by one of the enemy's shells on February 9th. Both the Royal Engineer officers in the siege were deeply indebted to him for his ever ready help and kindly suggestions. He was always ready to do anything to assist us in the siege, was often under fire, and was only killed in his own room after having been present throughout the day with the 4-inch gun in its duel with the enemy's 100-pounder.

D. S. MacInnes,
Lieut., R.E. (and Local Capt.).

APPENDIX.

ORIGINAL REPORT ON THE PROPOSED DEFENCE OF KIMBERLEY.

The general scheme of defence compiled by Col. Trotter, C.M.G., is to surround Kimberley with a girdle of small redoubts garrisoned with 50 to 100 men on a radius of about 1½ miles from the centre of the town, and at an average distance of ¾ mile apart. Retrenchments are formed at De Beers and Kimberley Mine enclosures.

It is proposed to divide the defence into five sections. To carry out the necessary works labour would be obtained from the De Beers Company; but as it would be difficult to employ large parties of natives with any prospect of attack while work was in progress, it is proposed that the redoubts should be constructed at once. I attach a tabular statement showing the work to be carried out in each section—first beforehand, second when an attack is expected. It will be seen from this that small parties are only required on the outside work after the redoubts have been completed. There will probably be no lack of volunteers from the Engineer Department to superintend the gang of labourers required. The larger parties required in the retrenchments would not be subject to sudden attack, and are close to their compounds. The De Beers Company have ample materials for carrying out the proposed defences.

Revetting Materials.—Old trucks, corrugated iron, sand bags, timber, steel plates.

Material for Obstacles.—Barbed wire, 3,000 yards, plain wire (unlimited supply). Some small trees for abattis will be available for Section D of defence.

Explosives.—*Dynamite* (*with electric detonators*).—The large stock of dynamite is now in sheds to the north-west of the town; it is under consideration whether this could not be buried in *débris* heaps outside the town.

COMMUNICATIONS.—The roads are good throughout. Telephonic communication already exists to most of the provision of the proposed defences, and can be quickly completed to other points. Ramps will have to be constructed to the various *débris* heaps selected for artillery position.

DEFENCES.—I attach a detail drawing of No. 4 Redoubt, which is fairly typical of the works. The permanent garrison is 50 men, but in accordance with instructions, I have designed the redoubts for a garrison of about 75 to 100 men to allow of their being reinforced if attacked. Machine gun positions are placed in each redoubt, though the guns would probably be kept in a central position in the first place. Parapets have been designed so that if necessary the third relief can be omitted.

I have arranged with the head of the Survey Department of the De Beers Company to take and mark the ranges round each position.

The demolitions required would be chiefly the removal of corrugated iron fences and native huts round the two retrenchments.

The sections of the defence are as follows:—

SECTION A.—KIMBERLEY MINE TO TRANSVAAL ROAD.—The redoubts form part of the retrenchments; it is proposed also to place shelter trenches at the most commanding points, as well as epaulments for field or machine guns. A sand bag parapet on top of the rock shaft gear frame will allow of a few rifles bringing in effect fire on the various roads. The barricades across the roads can be quickly made by haulage trucks filled with earth placed two or three deep across the road. They are at the right height for firing over.

It was intended to place a redoubt on Kimberley No. 1 *débris* heap, but this heap is too wet to allow of anything more than a low parapet being built. The chief engineer, Mr. Labram, states that he can arrange to run up a sufficient supply of dry earth to form a parapet, and a platform can be made of old planks and sand bags. This can therefore be used as an advanced position.

The positions best suitable for artillery are marked on the plan. I consider that a fence placed across the open ground from Mostert's to the railway essential to prevent a rush by mounted men.

SECTION B.—TRANSVAAL ROAD TO CONVICT STATION.—No. 3 Redoubt will have to be constructed with earth taken from the ditch in front of the parapet, as the heap is still too wet to allow of an interior trench. This, however, will not interfere with the strength of the work. There is no difficulty in constructing No. 4 Redoubt. The field of fire is good, except that trees along the Kenilworth Road require clearing.

Section C.—Convict Station to the Lodge.—The field of fire of the redoubts is good, but there is some unseen ground close to them due to the steep slopes of the heaps. It will, therefore, be necessary to surround with wire entanglement. The slaughter kraal in front requires demolition.

It is intended to defend De Beers enclosure similarly to Kimberley enclosure.

Section D.—The Lodge to No. 7 Redoubt.—It is necessary here to defend the Lodge and Sanatorium on the left of the Beaconsfield Road, and one house on the right of it. As artillery fire from the Bultfontein heaps may be expected, the first step would be to construct shelter trenches with light splinter-proof cover along the edge of the enclosure. Afterwards, if time permits, it will be necessary to put the houses in a state of defence. A reserve line of defence is also required along the Hospital enclosure and Hemming Street.

Section E.—No. 7 Redoubt to Kimberley Mine. — The redoubt is pushed forward so as to support Section D. The Reservoir enclosure is too large for a small garrison to defend effectively. I therefore propose to build a redoubt with the reservoir closing the gorge. To take full advantage of the Reservoir embankment a path would be made round it, and parapets placed on it at intervals. A parapet will also be constructed on the filter beds to command the Radloff Road.

Premier Mine.—This is intended as an isolated post. It is strong on the north, south, and east, but a deep cutting on the west side will require to be carefully blocked to prevent an enemy forming a lodgment. An artillery position will be made on the *débris* heap on the other side of the cutting. I am giving Major Turner a full statement of the labour, tools, and materials required from the De Beers Company, so that the necessary arrangements for them can be made.

I hope to be able to arrange with Mr. Labram for the careful organization of the parties required under heading (2). It will be necessary to have a section of Royal Engineers to generally assist, under a senior non-commissioned officer.

SECOND REPORT ON THE PROPOSED DEFENCES OF KIMBERLEY.

GENERAL SCHEME OF DEFENCE.—It is proposed to defend Kimberley by a reserve force kept in a central position ready to move in any direction. This force is to be supported by a girdle of small redoubts with a minimum garrison of 50 men. These redoubts are placed on a radius of about $1\frac{1}{2}$ miles from the centre of the town, and about $\frac{3}{4}$ mile apart.

The two mine enclosures—Kimberley and De Beers—are to act as retrenchments to the north-west and south-east sides of the town respectively. It is intended to hold the Premier Mine as an advanced position. I attach a detailed statement of the defence works to be executed, and show the working parties, materials, etc., required.

If all this work were to be left to the last moment, considering that the majority of the troops would have to be armed and equipped at the same time, confusion would result. It, therefore, seems to me absolutely essential if hostilities are expected that steps should be taken to carry out all the work possible beforehand.

I have, therefore, detailed the work under two heads :—

(1). Work which can be carried out at once.
(2). Work to be done on warning of attack.

The construction of each redoubt requires on the average a gang of 150 men for two shifts, and 100 men for a third shift, giving a total of 3,200 men for one shift, or, if the Premier Mine is included, 4,000 men.

The materials required are chiefly old material and corrugated iron, which, as bolting down would be unnecessary, would not be greatly damaged. There would also be some expense in connection with a temporary trolley line at the Reservoir, the putting up of wire fencing, and mining. I can furnish tracing of the plans of the redoubts when required. The working parties are worked out on a liberal scale, which would be necessary if they were to be constructed in a hurry, but, if done beforehand, the chief engineer would, no doubt, make his own arrangements to carry out the work, and a saving in men would be effected.

With regard to the second class of work, its success will entirely depend on organization beforehand.

The following appear to me to be the necessary steps :—

First.—Appointment of two members of the engineering staff of the company or other suitable volunteers to the charge of each section of defence.

Second.—Detailing of gangs of workmen, including artisans, to form the working party of each section.

The engineer in charge of each section will arrange for—

First.—Tools and materials required.

Second.—Organization of his gang into sections suitable for the work required.

Third.—Make himself thoroughly acquainted with the details of the work in his section.

If the materials and tools are not available from the company's stores, arrangements could, no doubt, be made to obtain them locally. The materials and tools should, as far as possible, be collected at a central spot in each section. If the whole of the works are to be left to the last, a much larger staff of skilled labour will be required, and careful plans beforehand still more necessary. The general work to be done in the defence is—

First.—Ranges taken and marked out for every point, and a plan and list made ready for the commander of each work.

Second.—Armoured trains got ready. There ought to be no difficulty in carrying this out in the shops if arrangements are made beforehand.

Third.—Sign posts put up to show the directions of the various points of the defence.

The distribution of the dynamite was mentioned by Col. Trotter to Mr. Labram, but no definite conclusion was come to. Action, at any rate, could be taken to stop further supplies coming in if hostilities become imminent.

The following is the work necessary in each section of the defence :—

Section A.—Kimberley Mine to Transvaal Road.—(1). (*a*). Two redoubts, Nos. 1 and 2. No difficulties in construction in these redoubts.

(*b*). Communications to artillery positions. There are four probable artillery positions to which ramps are required, and communications to them generally improved :—

1. At Kimberley No. 2.
2. At Kimberley No. 1.
3. Near the Compound to the north of Kimberley Enclosure.
4. On *débris* heaps to south-west of enclosure.

(*c*). Wire fence from Mostert's Farm to railway. This is most necessary to check a rush on the town between the redoubts.

(2). (*a*). *Kimberley Mine Enclosure.*—To put the old and new mine enclosures into a state of defence, I propose to put epaulments for guns and shelter trenches at suitable points, the total length being about 500 yards. The gear frame would have a sand-bag parapet placed on it. The corrugated iron fencing would have to be removed in some places and at other points defended. There is a great deal of demolition which ought to be carried out, such as small houses on the road to the west of the enclosure, which would afford cover to the attack. I have detailed 100 men as the party to do this, but if circumstances permitted, the party would be increased.

(*b*). *Barricades.*—Two main barricades are required in this section on the Barkly Road, but in addition to this the road would be blocked with wire, etc., in other places, and trucks held in readiness to block the mechanical haulage line and road alongside it. Two or three rows of trucks will make an efficient barricade.

(*c*). *Advanced Positions.*—These are shown on the map. Mr. Labram has visited No. 1 Kimberley with me, and knows what is required there.

(*d*). *Demolitions.*—*Vide* A above.

(*e*). *Mines.*—These are intended to be placed in the *débris* heaps to the south-west of the enclosure. They would require to be laid down by the mining staff.

SECTION B.—(1). (*a*). Two redoubts, Nos. 3 and 4. These redoubts are at De Beers, Nos. 7 and 8 and No. 1. There are no particular difficulties, but in the event of attack it will be necessary to remove the gearing frame. No. 1 heap is too soft for an interior trench to be dug in the redoubt.

(*b*). A wire fence under the fire of the redoubts is necessary round the engine house at No. 4.

(*c*). The artillery positions are at the Pulsator and on a *débris* heap near the Convict Station. At the former some work is necessary to form the ramps to the top of the heap.

(2). (*a*). The clearing of the trees along Kenilworth Road is of great importance. The trees would be used to form an abattis.

(*b*). The barricades are:—*First*, across the Transvaal Road at Mostert's Farm. The building here would be put in a state of defence as a picquet guard-room. *Second*, across the Kenilworth Road at the bend at the Reservoir.

(*c*). Shelter trenches are required on the *débris* heap marked A on the map for a section of men.

(*d*). Removal of the gear frame. Specially detailed men would be required for this.

(*e*). In the second relief the above work would be completed, and the field of fire of the redoubts improved. The stables would form good cover to an enemy if he got inside, but they might easily be held by a part of the reserve force.

SECTION C.—(1). (*a*). The two redoubts are on heaps which require some improvement. The sluits cut by the rain water will require filling in, and in the case of No. 5, the heap on its left will require to be leveled off on top.

(*b*). *Artillery Communications.*—The position for the guns are between No. 5 and 6 Redoubts and in rear of No. 6. Telephone lines to the redoubts are required.

(2). (*a*). *De Beers Mine Enclosure.*—This requires the same treatment as the Kimberley enclosure. The fence will require to be taken down, the Savoy Hotel, new engine house, and Compound put in a state of defence.

(*b*). *Barricades.*—These are on the Boshof Road and the Railway and Hull Street. Wire and trucks are required.

(*c*). *Demolitions.*—These consist of—*First*, removal of cow stables opposite No. 6 Redoubt. *Second*, general demolitions round De Beers enclosure. Any spare men would be employed on this in the second relief.

(*d*). The *débris* heaps to the north of the enclosure would be mined, to deny them to the enemy's artillery.

(*e*). The view from Nos. 5 and 6 Redoubts is restricted by other smaller heaps. It is necessary to make entanglement to prevent the enemy occupying the dead places.

SECTION D.—None of the work in this section can be done beforehand.

(1). The great difficulty here is the rocky nature of the ground. However, there ought to be enough earth in the gardens of the houses to make breastworks. If necessary, it can be added to from a *débris* heap in rear of the Lodge. The work required is—

(*a*). Put the Lodge in a state of defence.

(*b*). Put the Sanatorium in a state of defence.

(*c*). Put a house on the west side of the road in a state of defence.

The order of the work in each of these cases would be—First, make machine guns emplacement and shelter trenches along the fences of the houses facing towards Beaconsfield. Secondly, defend the houses by preparing loopholes, barricading doors, arranging for water and earth to put out fires, putting a sand-bag parapet on the verandah of the Sanatorium, and demolition of obstruction to the defenders' fire.

(*d*). The barricade would be placed near the tram shed to allow of it being flanked by the Sanatorium. The spare rails stacked there would be used for the barricade.

(*e*). *General Work* (such as cutting down trees in front, making abattis and rough entanglement in the interval).—If time permitted, a second line of defence would be made at Nazareth House, along the Hospital fence and Hemming Road. The main road would be again barricaded at that point.

SECTION E.—The same difficulty is met with here in rock being close to the surface. It will be necessary to run the greater part of the earth by truck or wagons from the *débris* heaps in rear. Special arrangements are therefore necessary. I do not know on whose property the proposed site of the redoubt is situated, but as this is the weakest point of the defence, the redoubt and work at the Reservoir should certainly be built beforehand.

(1). (*a*). *Parapet on the Filter Bed to cover Radlof Road.*—This will be made on the embankment of the bed.

(*b*). *Parapet in Reservoir Embankment.*—These will be made at intervals in the Embankment, so as to allow the small garrison to direct its fire wherever required.

(*c*). *Barricade on Radlof Road.*—In addition to the barricade, a trench is required for the reserve force to occupy if necessary.

(*d*). *Obstacles.*—The redoubt and intervals between it and the works on either side require well wiring to prevent a rush. There will probably not be time for more than a rough entanglement or trip wires.

(*e*). In the second relief the Native Camp would be demolished.

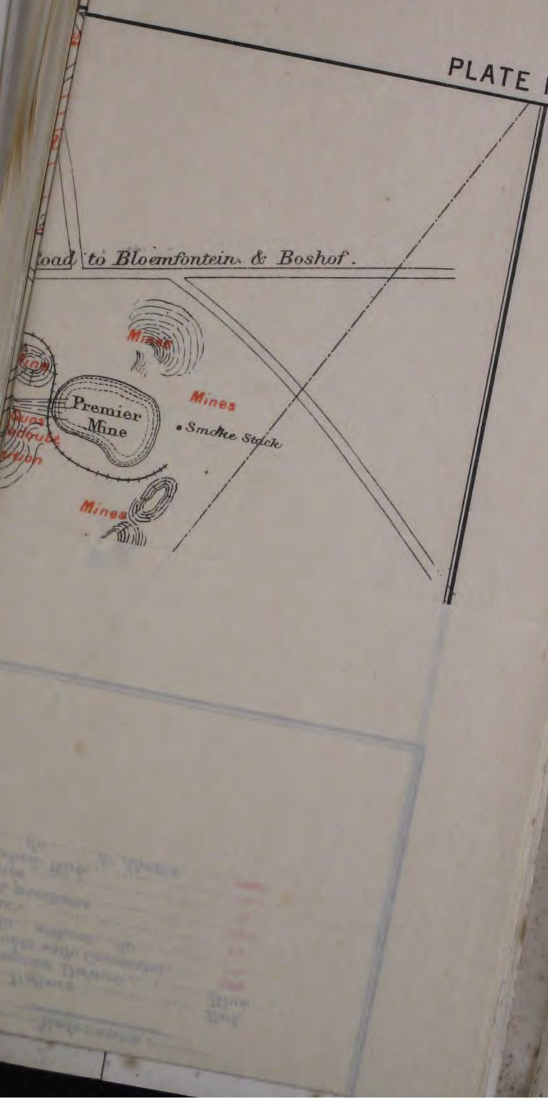
PREMIER MINE.—The work here would be placed on top of the *débris* heap used for the water supply. It will consist of a heavy breastwork placed along the edge, with splinter-proof cover on the east face. A platform for guns and shelter trenches for the escort will be placed on top of the *débris* heap now in use, and good communications made to it from the work.

(1). (*a*). The road between the two heaps must be completely blocked to the enemy.

(*b*). *Demolition.*—The Compound should be opened up to the fire from the trenches.

(*c*). *Mines.*—There are many smaller heaps about the main work which can well be mined.

PLATE I.



Road to Bloemfontein & Boshof.
Mines
Premier Mine
Mines
Smoke Stack
Mines

PAPER IV.

NOTE ON ROYAL ENGINEER DUTIES IN THE GERMAN ARMY.

BY MAJOR J. E. EDMONDS, R.E.

Introduction.

Genera Division of Duties.

THE duties performed in the British Empire by the Royal Engineers are carried out in Germany by several perfectly distinct bodies, as under :—

Permanent Fortification ...	By the Engineer Corps.		
Field Fortification, Siege Works, Pontooning ...	,,	Pioneer Battalions.	
Telegraphs	,,	Telegraph Battns.	Communication Troops.
Railway	,,	Railway Regiments	
Ballooning	,,	Balloon Battalion	
Barrack Building... ...	,,	Building Section of the Intendantur (military officials).	
Barrack Repair and Charge of Lands	,,	Garrison Administration Section of the Intendantur (military officials).	
Survey	,,	A Section of the Great General Staff.	
Submarine Mining ...	,,	Naval Artillery Detachments.	

The general relation of these bodies to the central authority may be seen at a glance from the table (p. 121).

Recent Changes.

The only important change which has taken place in "Engineer" organization in recent years has been the withdrawal of telegraph work from the pioneers, the formation of special telegraph battalions (1899), and the classing of these newly formed battalions, together with the railway and balloon units, as communication troops, under an Inspector, altogether independent of the Inspector-General of Engineers and Pioneers.

General Arrangement of Paper.

In the following pages the organization of each branch, and its relations to the War Office, general staff, etc., are treated separately, some comparison being made with the British service. A few details as to pay and the proportion of "Engineers" to the general total of the army are also given. It would appear, in consequence of the division into separate branches, that the German organization requires a larger number of officers and men to work it than our own demands.

Different Conditions in England and Germany.

It is perhaps desirable as preface to draw attention to some peculiarities of the German army. The peace conditions under which it works are very widely different from the British. Colour service is for two years only (cavalry and horse artillery three), so that the peace army is little better than an organized collection of instructors and recruits. Kiaochow is garrisoned by the navy, and the few men required for the other "colonies" are provided by paying high salaries to volunteers (p. 118).

The distribution of young officers among the various branches of the service is made not by competition, but on the lines of family connection or by the wishes of the individual, provided the regiment of his choice will elect him. It is only for the Kriegsakademie (Staff College) that there is, in conjunction with wholesale weeding out, a competitive examination.

Close on a quarter of a million of men join the colours annually in October; the shortness of the service makes it impossible, and the size of the contingent makes it unnecessary, to attempt to produce all-round men; every German officer and soldier is a specialist, and is trained to perform one class of work only. Service in the active army is one long course of instruction in the same garrison. Since it is found very difficult to get many men to stay on as N.C.O.'s beyond the regulation time, most of the instruction has to be done by the officers. The monotony of training recruits year after year without any change of station, with perhaps no prospect of promotion, naturally causes a number of officers to look around for some other career. This is provided for them in the War Office, in the Intendance, with its finance, building, supply, clothing, and administrative branches, and in the military law service. Ceasing to be officers, they become officials, continuing, however, to enjoy the privileges which a uniform confers in Germany. The lower grades in the same services afford places for ex-N.C.O.'s. From the Minister of War down to a supply clerk, every official connected with the army has "served."

Decentralization has been the keynote of German organization for over 80 years; the Empire is divided into 22 Army Corps Districts, in each of which the commanding general is the real and responsible head of all services. To ensure uniformity of training in the various branches there are inspectors for every arm, who visit the various Army Corps in turn, and report any variation they may observe to the Army Corps generals. As central authority the Emperor is assisted by a Military Cabinet, to which all Army Corps generals forward their reports. The Minister of War is merely the head of the administrative services, and the recorder of the Emperor's decisions; he only represents the army in the Reichstag in the absence of the Imperial Chancellor; to him report the Army Corps

Intendants. The Great General Staff deals with all strategic questions, mobilization, intelligence, and operations.

The Chief of the Military Cabinet, the War Minister, and the Chief of the General Staff have equal rank, and are independent of each other.

There will soon be an opportunity (in China) of judging how the German system works with an army beyond the seas.

NOTE.—The statistics which are given in this paper are those of Prussia, Wurtemberg, and the minor states, whose armies are administered by Prussia, that is, of 18 Army Corps, one of which, the Guard, is not territorial. The organization of the armies of Bavaria (3 Army Corps) and Saxony (2) is exactly similar to that of Prussia; but as these two states have separate budgets, army lists, etc., much additional labour, without particular profit, would have been involved by including their forces.

I.—THE CORPS OF ENGINEERS.

FORTIFICATIONS.

Corps of Engineers.

THE Corps of Engineers (Ingenieurkorps) contains officers only, the subordinate staff ranking as "officials." The members of it are employed on construction of fortifications, as officers "de place," and in charge of fortification districts, fortress telegraphs and electric lights, pigeon posts, demolition chambers in tunnels and bridges, and most of the fortress minor services. They also serve on technical committees and as instructors in the Staff College, the Engineer and Artillery School, the Construction (Fortification) School, and other educational establishments.

Head of the Corps.

The head of the corps is the Inspector-General of Engineers, Pioneers, and Fortresses. He has a Chief of Staff, four adjutants, a secretary, and six clerks. He conducts all affairs connected with the duties and *personnel* of the Engineers, with their military and technical training, and is consulted on all matters relating to fortresses which concern the Engineers. He is a member of the Defence Committee, and Joint President of the Artillery and Engineer School. He is not in the War Office.

War Office Control.

The portion of the War Office which deals with Engineer questions is the Engineer and Pioneer Section of the General War Department. This department has charge of matters concerning the formation, organization, etc., of the army, with a section for each arm. Under the Minister of War the Engineer and Pioneer Section arranges that all sums required for Engineer services are duly placed in the estimates, that all changes in *personnel* and organization authorized by the Emperor are duly announced in army orders, etc. Its control is purely formal, all matters being decided by the military authorities before they reach the War Office. The War Minister would merely point out, if necessary, that no funds were available.

Five officers and 6 officials are employed in the section. It has no equivalent in the English system, combining, as it does, part of the D.A.G.'s and part of the I.G.F.'s duty.

Relation of General Staff to the Corps.

The strategical *rôle* of fortresses, bridge heads, and demolitions, the consideration of the number and position of fortifications, the removal of those which are no longer necessary, and all similar questions are dealt with by Section 6 (Fortresses) of the General Staff, which employs 10—20 officers, under a field officer.

The Engineer Committee.

The technical side of these matters is the business of the Engineer Committee. This committee, which is not counted as part of the War Ministry, prepares projects for the construction and re-construction of fortifications, lays down general principles for working out the equipment of fortresses, and considers all new questions and inventions of fortification interest.

The object of the committee is therefore principally to keep Engineer matters up to date.

It has but slight resemblance to the R.E. Committee, for the members of it have no duties apart from those of the committee, and design fortifications in addition to conducting experiments and examining new inventions.

It consists of—

1 Colonel as President.
1 Adjutant to President.
2 Lieut.-Colonels as heads of sections.
4 Majors } as Members.
3 Captains }

Division of Corps into Three Districts and Seven Sub-districts.

For the decentralization of administration and execution of work the Engineer Corps is divided into 3 Engineer Inspections, or, as we should say, Districts, each under a major-general, with a staff of officers. The Engineer Inspections are sub-divided into 7 Fortress

Inspections, each under a lieut.-colonel, and each containing a group of fortresses. There is a major in charge of each fortress (see Tables (p. 99 *et seq.*) for details of places and numbers).

The Chiefs of the Fortress Inspections correspond to the British District C.R.E. (fortification side only). We have no exact equivalent to the 3 Engineer Inspections; the nearest would be the D.I.G.F. and 2 A.I.G.F.'s of the Fortification sub-division of the I.G.F.'s Office.

As will be seen from the table, some of the officers of the various inspections are employed on staff and instructional duties.

The Subordinate Staff.

The officers employed on fortification are assisted by 128 military foremen of works (Festungs bauwarte)—who are ex-non-commissioned officers of the Pioneers and rank as military "officials"—and 284 fortress warders (Wallmeister), who are ex-non-commissioned officers and men of various branches, who have received a special training. In addition to these there are some 200 to 300 probationers.

Duties of Engineer Officers.

It is the duty of the Engineer officers to make themselves thoroughly acquainted with the fortresses to which they are assigned, and with the surrounding country. In case of successful operations in an enemy's country, some of them would be assigned to the Staff for siege purposes; in 1870-71 many were taken to fill vacancies in the officers' corps of the Pioneers and on the Staff.

Officers of the Engineers are still liable to be transferred to the Pioneers, and *vice versâ*, but it is probable that this old custom will soon be stopped.

DISTRIBUTION OF THE ENGINEER CORPS.

Distribution of the Corps.

Inspector-General of Engineers, Pioneers, Fortresses (with Engineer Committee).

I.—Engineer Inspection.

Königsberg.

1 Major-General.
1 Captain.

1st Fortress Inspection.	2nd Fortress Inspection.
Königsberg.	*Kiel.*
1 Lieut.-Colonel.	1 Lieut.-Colonel.
2 Lieutenants.	1 Lieutenant.

Officers.

Königsberg	10	Friedrichsort	3
Dantzig	9	Cuxhaven	5
Pillau	2	Geestemunde	2
Feste Boyen	2	Wilhelmshaven	3
Memel	0	Swinemunde	4
		Heligoland	0
	23		17
Foremen of Works	21	Foremen of Works	15

Officers.

By Employment.		By Ranks.	
I.G.F. Staff	2	General	1
Engineer Committee	4	Colonels	2
Engineer Inspection Staff	2	Lieut.-Colonels	4
Fortress Inspection Staff	5	Majors	14
1st Fortress Inspection	23	Captains	14
2nd Fortress Inspection	17	Lieutenants	22
Instructors	4	2nd Lieutenants	4
General Staff	1		
Telegraphs	3		
	61		61
		Foremen	36

DISTRIBUTION OF THE ENGINEER CORPS.—*Continued.*

II.—Engineer Inspection.

Berlin.

1 Major-General.
1 Captain.

3rd Fortress Inspection.	4th Fortress Inspection.
Posen.	*Thorn.*
1 Lieut.-Colonel.	1 Lieut.-Colonel.
1 Lieutenant.	1 Lieutenant.

Officers.

Posen	11	Thorn	9
Glogau	3	Graudenz	6
Neisse	1	Kustrin	5
Glatz	2	Spandau...	2
		Magdeburg	2
	17		24
Foremen of Works	14	Foremen of Works	20

Officers.

By Employment.		*By Ranks.*	
I.G.F. Staff	2	Generals...	1
Engineer Committee	3	Colonels	0
Engineer Inspection Staff	2	Lieut.-Colonels	2
Fortress Inspection Staff	4	Majors	12
3rd Fortress Inspection	17	Captains...	19
4th Fortress Inspection	24	Lieutenants	28
Instructors	11	2nd Lieutenants	4
General Staff...	1		
Telegraphs	2		
	66		66
		Foremen of Works	34

ISTRIBUTION OF THE ENGINEER CORPS.—*Continued.*

III.—Engineer Inspection.

Cologne.

1 Major-General.
2 Lieutenants.

h Fortress Inspection.	6th Fortress Inspection.	7th Fortress Inspection.
Strasburg.	*Metz.*	*Cologne.*
1 Colonel.	1 Lieut.-Colonel.	1 Colonel.
1 Lieutenant.	1 Lieutenant.	1 Lieutenant.

Officers.

rasburg	14	Metz	14	Cologne	8
u Brisach	5	Thionville	4	Coblenz	2
m	5			Mainz	6
sch	0			Wesel	2
	24		18		18
remen of Works	16	Foremen of Works	14	Foremen of Works	19

Officers.

By Employment.		*By Ranks.*	
.F. Staff	0	Generals...	1
gineer Committee	2	Colonels	2
gineer Inspection Staff	3	Lieut.-Colonels	1
rtress Inspection Staff	6	Majors	10
h Fortress Inspection	24	Captains...	26
h Fortress Inspection	18	Lieutenants	36
h Fortress Inspection	18	2nd Lieutenants	5
structors	7		
neral Staff...	2		
legraphs	1		
	81		1
		Foremen of Works	49
		Staff (Engineer Committee) ...	9

Totals.

Officers	208
Foremen of Works	128
Warders...	284

II.—THE PIONEERS.

Field Fortification, Pontooning, and Siege Works.

The Pioneers. The Pioneers (Pioniere) represent the British Field Companies, Bridging Battalion, and Fortress Companies.

They are organized in battalions, of which there are 20 for the 18 Army Corps (3 Army Corps, I., XV., and XVI., have 2, and the XI. Army Corps is at present without one).

In peace each battalion has 4 companies. The men serve 2 years, and the whole time is taken up by instruction.

On mobilization each battalion with its reserves forms—

(1). Staff which joins the Staff of the Army Corps (Corps Engineer and Assistant, etc.).

(2). Three field companies, 1 for each division and 1 reserve.

(3). Bridge trains :—

- (*a*). One corps bridge train.
- (*b*). Two divisional bridge trains attached to the field companies.

(4). Two siege companies.

(5). Pioneer detachment (in certain battalions) for a cavalry division.

Detachments for the fortresses will probably be formed from the 2nd Battalions of the I., XV., and XVI. Army Corps mentioned above, which are stationed at the fortresses of Konigsberg, Metz, and Strasburg.

Training. Up to a certain point the training of all the men is the same; they are partially trained as infantry, and as such attend brigade manœuvres; they are all trained in fieldworks, but the men for the siege companies spend more time at siege works and less at bridging than the others. The garrisons of the Pioneer battalions are all on rivers suitable for bridging operations.

The waggons and vehicles of the pioneers are horsed and driven by the Train, under Train officers, so that no drivers have to be instructed, and the Pioneer officers have no stable duties.

The head of the corps is the Inspector-General of Engineers, Pioneers, and Fortresses; the same section of the War Office which takes charge of Engineer matters deals with the Pioneer business. Head of the Pioneers.

The Inspector-General is assisted in his duties by 3 Pioneer "Inspections," each with a major-general, with one captain and one lieutenant as adjutants, at the head of it. Each inspector watches over the *technical instruction* of 6 or 7 battalions. In I., XV., and XVI. Army Corps there is a colonel, who acts as regimental commander to the 2 battalions. Division into Three Portions.

For the purposes of *discipline, general training, and manœuvres* the Pioneer battalions are under the orders of the commander of the Army Corps to which they belong. Battalions are under the Army Corps Generals.

The actual strength of the Prussian Pioneer Corps in peace time is (1899):— Strength.

Officers—

Major-General	3 Inspectors.
Colonels	3
Lieut.-Colonels	2 (1 Engineer Committee).
Majors	26
Captains	95
Lieutenants	50
2nd Lieutenants	230
" "	108 (under instruction).
	517

Men (Budget)—

Non-Commissioned Officers ...	2,736
Privates	8,664 (all under instruction).
Tradesmen	106 (for making clothing).
	11,506

The Wurtemberg battalion has—

21 officers.
117 non-commissioned officers.
379 privates.

Each Prussian battalion has, roughly—

Commander	1
Field Officer or 5th Captain	1
Captains	4
Lieutenants	4
2nd Lieutenants	13–14
Doctors	2
Paymaster	1
Paymaster-Assistant	1
Armourer	1
Non-Commissioned Officers	79
Drummers	13
Men	508
Tradesmen	6
Hospital Attendants	4

War Formations.

A *Field Company* on a war footing has—

5 officers.
213 men.

The Divisional Bridge Train—

2 officers.
52 men.
6 pontoons, and
4 trestles, or
120 feet of bridge.

Corps Bridge Train—

5 officers.
190 men.
26 pontoons, and
6 trestles, or
431 feet of bridge.

So that a Prussian Army Corps has— Amount of Bridge Train.

	Officers.	Men.	Pontoons.
ps Bridge Train	5	190	26
ivisional Bridge Trains	4	104	12
ioneer Companies...	15	639	—
	24	933	38

A British Army Corps (3 divisions, but take 2 for comparison) —

	Officers.	Men.	Pontoons.
dging Battalion, a troop	3	211	16
eld Companies (6 officers, 210 men)	18	630	6
	21	841	22

The *Siege Companies* have—

5 officers.
213 men.

The *Pioneer Detachment for Cavalry Division*— Mounted Detachments.

1 officer.
30 men.

The men of these detachments will be carried on carts or mounted bicycles.

III.—THE COMMUNICATION TROOPS (VERKEHR-STRUPPEN).

Telegraphs, Railways, and Balloons.

Formation of Communication Troops.

In 1899 the telegraph troops were withdrawn from the command of the Inspector-General of Engineers, Pioneers, and Fortification, and, with the Railway and Balloon units, which had been placed under a separate Inspector some years previously, were classed as Communication Troops, at the head of whom is the Inspector of Communication Troops, with the rank of General of Division. This step is entirely in consonance with the German ideas of decentralization and specializing.

The Inspector of Communication Troops.

The staff of the Inspector of Communications consists of one staff officer and one adjutant.

Control by Great General Staff.

The Inspection of Communication Troops is immediately subordinate to the Chief of the Great General Staff, and the administration of it does not come within the ken of the War Minister. It is controlled by a Quartermaster-General, who has for his assistance an "Abtheilung"* for organization and *matériel* matters, and a "Sektion" for *personnel* questions. The number of officers employed in these offices is not published; as there are 134 officers employed in the 10 sub-divisions of the Great General Staff, it may be 10 or 20.

Telegraph Troops.

Telegraph Troops.

Telegraph matters are placed under an Inspector of Telegraphs who has the rank of regiment commander. He has 1 adjutant.

The Prussian telegraph troops number (budget 1900)—

Inspector	1
Field Officers	3
Captains	11
Lieutenants	8
2nd Lieutenants	18
Total officers	41
N.C.O.'s	216
Men	912
Tradesmen	8
Total rank and file	1136

* The nearest approach we have to this is the Army Railway Council.

They are formed into 3 battalions of 3 companies each, with a letachment for the Cavalry Telegraph School (which gives instruction in telegraphy, tapping wires, demolition, etc., to cavalry classes).

The vehicles are horsed by the Train, who furnish in peace—

132 officers and men, and
169 horses

for the purpose.

The men serve 2 years, and are recruited from the employés of the State telegraphs and the electrical trades; all they require is a military-technical training.

The following are the war formations:—

War Formations.

A section is formed for each division, army corps, and army.

	Officers.	Men.	Bare Wire. Miles.	Cable. Miles.	Poles.
An *Army Section* consists of ...	4	168	$72\frac{1}{2}$	$10\frac{1}{5}$	1296
Army Corps Section	4	146	15	$7\frac{1}{2}$	?
2 *Divisional Sections*	—	14	?	5	—

The $\frac{1}{2}$ Telegraph Battalion of a British Army Corps has—

7 officers.
239 men.
60 miles of air line.
32 miles of cable.—(*Manual of Telegraphy*).

The fortress telegraph systems, as already noted, are in charge of the Engineer Corps.

Railways.

Railway Section of Great General Staff.

For the management of railway matters, and the conduct of railway service during the recruiting and dismissal season, manœuvres, mobilization, and war, the agents of the Railway Abtheilung of the Great General Staff are—

(1). The railway commissioners (1 lieut.-colonel, 1 major, and 4 captains).

(2). The railway line-commissioners (3 colonels, 11 majors, 2 captains, and 16 civilian officials), each pair of whom (1 officer and 1 civilian) have a section of the Prussian railways under their care.

There is also a committee of 6 officers for carrying out experiments.

Railway Troops.

Railway Troops.

The Prussian railway troops number in peace—

	1	brigade commander.
	3	regiment commanders.
	12	field officers.
	31	captains.
	30	lieutenants.
	62	2nd lieutenants.
	18	2nd lieutenants under instruction.
Officers	157	
	994	non-commissioned officers.
	2806	men.
	18	tradesmen.
	3818	

They form a brigade of 3 regiments, each of 2 battalions, and a traffic section of 3 companies, commanded by a major-general, with 2 adjutants.

As already stated, the brigade is immediately under the Chief of the General Staff. To it is attached the Balloon Battalion and the Experiment Committee.

The staff of a regiment consists of—

1 commander.
1 field officer.
1 captain.
1 lieutenant.
4 doctors.
1 paymaster.
10 non-commissioned officers.
21 bandsmen.
18 tradesmen.

The strength of a battalion in peace is—

1 field officer.
4 captains.
4 lieutenants.
13 2nd lieutenants.
1 doctor.
1 assistant paymaster.
85 non-commissioned officers.
512 men.

The traffic section works the Berlin-Juterbog Railway, which is about 40 miles long.

War Formations.

On *mobilization* the brigade is broken up and forms—

(1). Railway construction companies, each of 9 officers and 222 men.
(2). Railway traffic companies, each of 6 officers and 206 men.
(3). Railway workmen companies, each of 2 officers and 202 men.

The construction companies absorb the greater part of the men of the peace establishments of the railway regiments.

The traffic and workmen companies are largely formed of reserve officers and men.

BALLOONS.

Balloon Troops.

The Balloon Battalion consists of 2 companies, with—

1 field officer.
3 captains.
3 lieutenants
3 2nd lieutenants.
1 paymaster.
1 paymaster assistant.
1 æronaut.
37 non-commissioned officers.
240 men.
1 hospital attendant.

A large number of officers and men are in addition passed through the school.

In *war* a field balloon detachment consists of 2 balloons, with 4 charges of gas, etc.. Extra gas is brought up in "gas-columns." The number of detachments to be formed is not published.

ROAD TRACTION.

Automobiles. Road Traction.

The railway regiment is experimenting with road traction and automobiles, but no units have yet been formed.

IV.—THE GARRISON ADMINISTRATION AND OFFICE OF WORKS.

CONSTRUCTION AND REPAIR OF BARRACKS, CARE OF WAR DEPARTMENT LANDS, ETC.

Garrison Administrations.

The work of the R.E. barrack divisions is carried out in Germany by the Garrison Administration and Office of Works (Garnison verwaltung und Bauwesen) Section of the Intendantur. Its *personnel* consists of military officials (Beamte), as distinguished from military officers. They are drawn from the following classes :—

Staff.

(*a*). The higher officials :—

(1). Army officers who have served 6 years.
(2). Reserve officers with proper qualifications.

(*b*). Technical subordinate staff :—

(1). Soldiers serving who have matriculated at a classical or modern school.
(2). Non-commissioned officers of 12 years' service, with excellent character and good education.

For all classes there are courses of instruction, examinations, and probationary periods.

Organization.

In every Army Corps District there is a Garrison Administration and Office of Works Section, with a Building Councillor (Baurath) at the head of it. He is responsible to the Intendant of the Army Corps, who is the adviser of the Army Corps commander on all non-combatant matters.

Two Branches.

The section has two branches, each with separate *personnel*.

(1). The *Garrison Administration* combines certain Army Service Corps and R.E. duties. All requisitions concerning barracks, quarters, repairs, barrack stores, and lands are sent to it direct. It deals with the allotment, equipment, and maintenance in good order of barracks, guard-rooms, stores, minor buildings, ranges, manœuvre and parade grounds, etc. (except hospitals, for which a medical section is responsible).

There are 245 such administrations in Prussia, that is about 14 in each Army Corps District.

(2). The *Garrison Office of Works* assists the administration section with technical advice, and undertakes the execution of all buildings, etc., which are not fortifications. It draws up plans and invites tenders. The actual construction is done by civilian contractors, under the superintendence of works officials. Any service under £1,500 may be undertaken by an Army Corps Intendant without special War Office approval.

In each Army Corps District there are from 3 to 6 building circles (Baukreise), each with a definite sub-district.

The Staff of the Prussian Garrison Administration consists of (Budget, 1900)— Strength.

43	Directors,	Higher Officials.
31	1st Class Inspectors,	Higher Officials.
224	2nd Class ,,	Higher Officials.
403	Barrack Inspectors,	
1,044	Barrack Warders,	
2	Head Washmen,	
43	Engine Drivers,	

with a large number of probationers, who, since 1899, wear a special uniform.

The Staff of the Building Branch is—

25	Building Councillors,	Higher Officials.
82	Building Inspectors,	Higher Officials.
41	Building Inspectors (special works),	Higher Officials.
82	Foremen of Works,	
82	Clerks and Draughtsmen;	

and £7,632 is voted for special assistance.

In a single Army Corps—the V. (containing 24 battalions of 570 men, 20 squadrons, 24 batteries, 4 companies of pioneers, and 3 of Train) is taken as an example—there are for the 17 garrisons* :— Example of Army Corps.

Garrison Administration.

2	Directors,	Higher Class Officials.		
13	Inspectors,	Higher Class Officials.		
20	Barrack Inspectors,	2nd	,,	,,
63	Barrack Warders,	3rd	,,	,,
(?)	Probationers (numbers not published).			

* Three of these garrisons are small, and contain one battalion, 570 men only. They are administered from the regimental headquarters, so for organization there are practically only 14 garrisons.

Office of Works.

2 Building Councillors, 3 Building Inspectors,	Higher Class Officials.
4 Foremen of Works, 4 Clerks and Draughtsmen,	2nd Class Officials.

who are divided among 4 building circles, and £450 is voted for assistance.

Example of Garrison.

In a single garrison Posen, headquarters of V. Army Corps, and, therefore, the central office of the administrative services of the corps, is taken as an example (garrison 9 battalions, 5 squadrons, 6 batteries) :—

	Garrison Administration.	Office of Works.
Higher Officials	2	4
2nd Class Officials...	14	4
3rd Class Officials...	25	Engaged and paid as required.

Relations with War Office.

All matters connected with barracks and lands are under the Minister of War, who is the head of the administrative services. He controls the *personnel* through the Intendantur Section (7 officials) of his Central Department, and technical matters through the Army Administration Department, which has the following sections and staff :—

	Army Officers.	Officials.	
		I. Class	II. Class.
Staff	2	—	—
Finance Section	—	4	13
Supply	—	5	28
Clothing	3	1	9
Barrack Administration...	3	3	18
Building	—	6	5

The Intendant of an Army Corps may, if he see fit, refer any decision of the Army Corps General to the Minister of War, who for technical matters is his hierarchal chief. The General, however, corresponds direct with the Military Cabinet of the Emperor. Practically, nearly everything is settled in the Army Corps, and, as with the combatant branches of the service, the War Office provides only the necessary funds, and records changes, reporting irregularities to the Emperor.

V.—GENERAL STAFF.

SURVEY (LANDESAUFNAHME).

The Survey is placed under the Chief of the General Staff, and is managed by one of the 4 quartermaster-generals as Chief of the Survey. This is much as if Section F of the Intelligence Division controlled Southampton and the R.E. survey companies. Chief of the Survey.

The Chief of the Survey has 1 adjutant, and is assisted by the following officers :— Staff.

1 major-general.
2 colonels.
3 majors.
11 captains.
—
17

The Survey Department is divided into the— Organization.

(1). Trigonometrical section.
(2). Topographical section.
(3). Cartographical section for printing and reproduction.
(4). The map room.

Maps of foreign countries are prepared and guarded in a special section of the Great General Staff, but are reproduced by the cartographical section of the Survey.

There are no survey companies. Hitherto no important military operations have been undertaken in unsurveyed countries, but a detachment consisting of 2 naval and 3 military officers, with civilian assistants, is at work at Kiaochou. It is not known whether there are survey parties in the other colonial possessions. No detachment has been detailed for the Peking force. No Survey Companies.

Strength of *Personnel.*

The civilian *personnel* of the Survey consists of the following officials :—

Central Office	3
Plan-Room Inspector	1
Survey Directors	5
Surveyors and Draughtsmen	122
Assistant " "	25
Engravers, Lithographers, and Photographers ...	36
Assistant " " "	15
Printers and Galvanizers	12
Assistant "	14
Clerks and Secretaries	20
Assistant "	4
Messengers and Porters	17
	274

The map room is in charge of a retired major.

VI.—THE NAVAL ARTILLERY.

SUBMARINE MINING.

Naval Artillery Divisions.

The coast defences of Germany are entrusted to the navy. Special troops who never serve on board ship, but are commanded by naval officers, are raised to man them. These troops are called Naval Artillery Divisions (Matrosen Artillerie Abtheilungen), and are trained both as artillerymen and as submarine miners.

There are 4 Naval Artillery Divisions :—

(1). Friedrichsort ... ... with 4 companies.
(2). Wilhelmshaven ... ... " 3 "
(3). Lehe (for Geestemunde) ... .. " 3 "
(4). Cuxhaven ... ... " 3 "

No. 3 provides a small detachment for Heligoland.

Each division is commanded by a naval captain, with a lieutenant as adjutant. Each company has a naval commander as captain and 2 lieutenants.

Head of N.A. Divisions.

For technical purposes the naval artillery are under the Inspector of Marine Artillery, an admiral, who is also Inspector of the School of Gunnery. He has a staff of 2 naval captains, an ordnance captain, and a gunnery lieutenant.

For other purposes the naval artillery are under the orders of the commandant of the fortress to which they belong. This officer has the usual staff—a brigade major and assistant brigade major (naval officers), and 2 to 4 military Engineer officers.

Strength.

The peace strength of naval artillery (Budget, 1899), is—

Inspector and Staff	5
Commanders of Divisions	4
Adjutants ,, ...	4
Company Officers	39
	52
Petty Officers	26
Non-Commissioned Officers	226
Privates, 1st Class	390
Privates, 2nd Class	1,556
	2,198

There are also—

177 reserve officers, and
29 landwehr officers

of the naval artillery, and some

2,600 reserve men, and
2,800 landwehr men.

Source of Recruits. Training.

The men are recruited from river boatmen, smiths, and other suitable trades; they serve for 3 years. Their training each year is as follows:—

Infantry, Drill, and Gymnastics	2 months.
Artillery	5 ,,
Submarine Mining, including Returning Stores	3 ,,
Infantry and Artillery Drills	2 ,,
	12 months.

For submarine mining they form the laying-out squads, water parties, and shore parties; the laying-out vessels with engine drivers are provided by the torpedo divisions of the navy; the electric lights and telegraphic communications are managed by the military

Storekeepers. engineers of the fortress, and the stores (including reserves), which take up so much of a British submarine miner's time, are prepared and cared for by a special branch called the Inspection of Marine Depôts.

Marine Depôt Inspector. The head of this Inspection is an admiral or a naval captain, with a staff of 1 lieutenant, 1 ordnance captain, and a torpedo lieutenant. He has under his charge the artillery depôts for stores and ammunition, as well as the mine depôts (Minen depôts).

There is an artillery depôt and a mine depôt, both under one naval captain, at each of the four fortresses already mentioned. The officers of these depôts are all men who have risen from the ranks of the navy, and are distinguished from the ordinary officers by the word torpeder, usually abbreviated to T., being placed before their rank, *e.g.*, torpedo commander or T. commander.

There are at the mine depôts—

Friedrichsort	5 T. officers.
Wilhelmshaven	4 "
Lehe	3 "
Cuxhaven	3 "
	15

the senior at each being a T. commander.

There are also—

22 warrant officers.
36 petty officers.

58

Giving 15 warrant and petty officers to each station; they are assisted by a number of probationers (Lehrlinge). The *personnel* of the mine depôt represent the storekeepers and electrical specialists of our service.

Experiment Committee. There is a Submarine Mining Experiment Committee (Minenversuch Kommission), consisting of a naval captain, 3 commanders, and 3 lieutenants, who appear to have no other duty, and have under their charge an experiment ship.

Control by the Admiralty. As regards administration by the Admiralty, the *personnel* are under the military section of the General Marine Department and the stores under the equipment section of the Technical Department, but both the Inspector of Marine Artillery and the Inspector of Depôts may report direct to the Minister of Marine.

APPENDIX I.

PAY.

In comparing the German rates of pay with our own it must be borne in mind that life in Germany is far cheaper than in England. The Kriegs-Ministerium permits a captain, 1st Class, whose pay is £239 16s. a year, all told, to marry without any private means. It is considered that for the above sum a married officer can maintain his position respectably ; 2½ to 3 times the amount would be the least English equivalent.

Table of Yearly Pay.

	Pay.	Allowances.*	Total.	
Engineers, Pioneers, Telegraph, Balloons, and Railway Troops, etc. (Same as Cavalry and Field Artillery, and a trifle more than the Infantry and Train).				
	£	£ s.	£ s.	
Inspector-General	1200	152 10	1352 10	With house fully equipped and forage for 5 horses.
Engineer and Pioneer Inspectors.	495	117 16	612 16	Forage for 3 horses.
Fortress Inspectors and Lt.-Cols. (C.R.E.).	390	92 8	482 8	Forage for 2 horses.
Major	285	65 4	350 4	do. do.
Captain, 1st Class	195	59 16	254 16	Forage for 1 horse
Lieutenant	113	34 2	147 2	
2nd Lieutenant	59	34 2	93 2	
Barrack Construction.				
Building Councillor (C.R.E.)	360	24 12	384 12	
Garrison Inspector (Division Officer).	285	24 12	309 12	

* These vary slightly according to garrison. A mean has been taken.

TABLE OF YEARLY PAY.—*Continued.*

	Pay.	Allowances.*	Total.	
Care of Lands and Repairs.				
	£ s.	£ s.	£ s.	
Director (Sub-Dist. C.R.E.)	210 0	38 8	247 8	
Inspector (D.O.)	165 0	29 18	194 18	
Survey.				
Chief of Survey	495 0	148 4	643 4	Forage for 5 horses.
Assistant Chiefs	390 0	97 16	487 16	Forage for 3 horses.
Survey Director (O.C. Co.)...	300 0	24 12	324 12	
Submarine Mining.				
D.O.S.M. and Detachment Commander.	312 10	73 4	385 14	
Officer Commanding Company	210 0	73 4	283 4	
Lieutenant	84 0	38 12	122 12	
General Staff of Army. (For comparison).				
Colonel or Lt.-Col. ...	390 0 to 495 0	114 18 to 148 4	404 18 to 643 4	Forage from 5 to 2 horses.
Major or Captain.. ...	135 0 to 292 0	84 10	219 10 to 376 10	Forage from 3 to 1 horses.
Troops in Colonies and Protectorates.				
Major	629 0	15 0	644 0	With quarters and forage.
Captain	480 0	15 0	495 0	
Lieutenant	360 0	15 0	375 0	
2nd Lieutenant	300 0	15 0	315 0	

* These vary slightly according to garrison. A mean has been taken.

APPENDIX II.

SUMMARY OF NUMBERS DOING R.E. WORK.

	Officers.	Officials, 1st Class.	N.C.O.'s.	Officials, 2nd Class.	Men.
Engineers	208	—	—	412	—
Pioneers :—					
Prussia	517	—	2,736	—	8,760
Wurtemburg	21	—	117	—	379
Telegraph :—					
Prussia	41	—	216	—	920
Wurtemburg	—	—	9	—	40
Railways	157	—	994	—	2,824
Balloons	22* 10†	— —	— —	— —	— —
Barrack Construction	—	154	—	169	—
Lands and Repairs‡	—	150	—	705	—
Survey	17	131	—	143	—
Submarine Mining Troops§ ...	13	—	63	—	486
Submarine Mining Store Depôts	18	—	58	—	—
	1,044‖	435	4,193	1,429	13,409
	$\underbrace{\hspace{3em}}_{1,479}$		$\underbrace{\hspace{6em}}_{19,031}$		

* Railway Commissioners.
† Great General Staff.
‡ Half total of Garnison Verwaltung officials taken, as they have other duties.
§ One-fourth of Naval Artillery detachments taken.
‖ War strength, including reserve and landwehr officers, is about double this.

APPENDIX III.

COMPARISON OF TOTALS (PEACE STRENGTH) OF BRITISH EMPIRE AND GERMANY (EXCLUDING SAXONY AND BAVARIA).

	Officers and Officials doing R.E. Work.	N.C.O.'s, Men and Lower Officials doing R.E. Work.	Total Army, 18 Army Corps.
Germany	1,479	19,031	466,074
	20,510		
	Proportion 20,510 to 466,074 is 1 : 22.		
Great Britain and Colonies:—*			
Regulars...	588	7,637	158,318
	47†	650‡	—
India:—			
Regulars...	370	74	70,489
Natives	62	3,966	141,397
	1,167	12,327	370,204
	13,594		
	Proportion 13,594 to 370,204 is 1 : 27.		

* Budget, 1899-1900.
† Surveyors.
‡ Staff Engineer Services.

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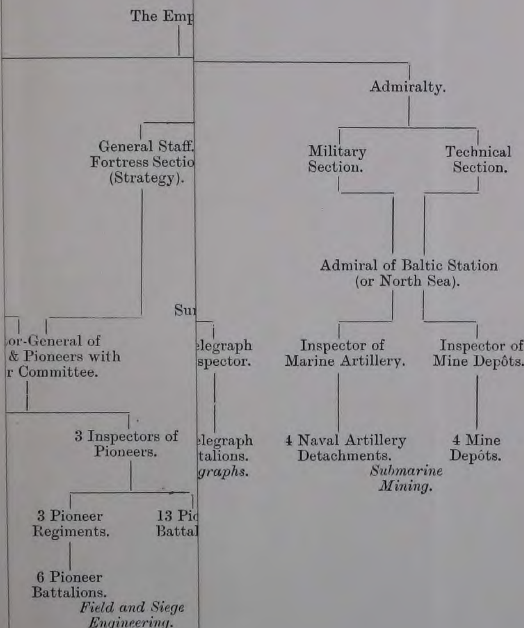


PAPER V.

EARTH SLIPS IN BANKS AND CUTTINGS, AND HOW TO PREVENT OR REMEDY.

BY R. ELLIOTT COOPER, ESQ., M. INS. C.E.

THE subject of slips in earthwork, whether in banks or cuttings of a railway, is one of very great importance, not only in connection with the actual construction of the line, but also in relation to its maintenance after it has been opened for traffic; and it often occurs that a saving in the original construction entails a large annual expenditure in maintenance far exceeding, in a few years, any economy which was effected in the first instance.

Moreover, in laying out a new railway the selection of a route is sometimes confined to very narrow limits, and there is little possibility of deviating to any extent, in which case there is no alternative but to adopt a route where it is obvious from the first that the nature of the ground is such that slips are almost certain to take place unless the greatest precautions are taken.

It therefore becomes an important part of an engineer's duty, in carrying out earthworks of any magnitude, to make a careful study of the geological formation encountered, and to watch for any indications which would assist him in deciding upon the precautionary measures to be taken to minimize the possibility of slips occurring.

It, however, frequently happens that slopes which were considered perfectly secure, and had stood for many years, have suddenly slipped from causes which could not have been foreseen at the time of construction; and in this case it is essential to take prompt remedial measures and the most suitable steps, according to the nature of the ground, to prevent further developments.

Some idea of the importance of a careful study of these points in the early stages of railway construction may be gathered from a case which recently came under the notice of the writer in connection with a Colonial railway.

In constructing the line the slips were of such an extensive character that it was found impossible to keep the cuttings open, in consequence of which, although the earthwork was practically completed, it was decided to deviate the line for a distance of 3 or 4 miles. The wisdom of so doing was clearly demonstrated by the fact that the movement continued to such an extent on the abandoned line that eventually no trace of the works could be seen.

The angle, or inclinations, at which embankments and cuttings will under ordinary conditions stand vary, of course, with the nature of the strata cut through. In hard sand, shale, or hard clay, which is usually intersected by bands of rock, the sides of the cuttings will stand at 1 to 1, and the material excavated, when put into bank, will stand at $1\frac{1}{2}$ to 1, or, to put it in another way, the cuttings will stand at 45 degrees from the horizontal, and the banks at 34 degrees.

Figs. 1 and 2 show cuttings and banks with slopes at these inclinations, and the view illustrates a deep cutting near Chesterfield constructed with these slopes.

It by no means follows, however, that all kinds of strata will stand with slopes at anything like these angles. London clay, for instance, requires inclinations of from 2 to 3 to 1, or angles from the horizontal of from 30 to $18\frac{1}{2}$ degrees, and serious slips have occurred even with such flat slopes.

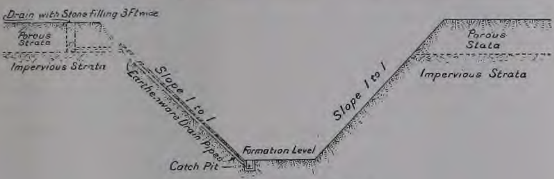
In marl, slopes of about $1\frac{1}{2}$ to 1 will usually stand, except where they are affected by the presence of water.

The writer was lately called in in connection with some extensive slips in a marl cutting, which had been excavated with slopes of 1 to 1, the remedying of which entailed a large expenditure.

Plates I. and II. show the work carried out after the slips occurred, and what should have been done in the first instance as a preventative.

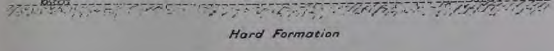
Slips in cuttings are occasioned by a greater diversity of causes than in the cases of slips in embankments.

One of the chief causes is that of water percolating from the surface through the porous ground until a more or less impervious strata is reached; the water then collects at this level, and gradually forces its way to the face of the slope. Little by little the water undermines the overlaying mass, which then slides forward.



TRANSVERSE SECTION.

Fig. 1.



TRANSVERSE SECTION.

Fig. 2.

Fig. 1 shows the method of drainage which, generally speaking, it is best to adopt in cases of this kind to prevent the first movement.

This form of slip usually occurs when the line of the cutting is at right angles to sloping ground. The preventative measures which should be adopted are very simple, and are as follows:—

A deep drain should be cut parallel to and about 10 feet from the top of the slope. This drain should be carried down, generally speaking, to the level of the impervious strata, and filled with stone or other dry material. A drain at right angles to this should be cut up the slope of sufficient depth to intersect it. This should have earthenware drain pipes laid in the bottom and the grip filled in with stone, and be connected with a catch-pit at formation level alongside the line.

There are, however, many cases where preventative measures of this kind would be of no avail. In the coal measures districts it often happens that the cuttings are carried through ground intersected by layers of rock tilted at various angles. When the inclination is steeper than 18 degrees there is the chance of the overlaying mass of soft material slipping down, especially if the layer of rock is lubricated by the action of water.

In a slip of this nature in Derbyshire about 30,000 cubic yards slipped down into the cutting. As in this case the material could be utilized in filling up a station site, it was not considered desirable to incur the great expense of stopping the slip when the movement first took place by building strong walls along the foot of the slope, which is a very effective form of remedy where the pressure from the sliding mass is not too great.

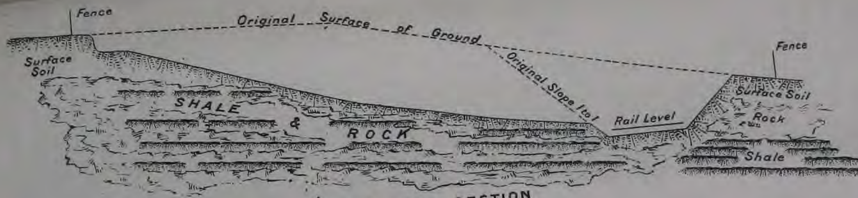
The cutting as originally proposed to be excavated, and as it was after the slip occurred, is shewn on *Figs.* 3 and 4.

Walls along the foot of the slope would probably have held up the sliding mass, provided the remedy had been applied before any great movement had taken place, but would have been costly.

Walls of this description should be built of stone without mortar, not only as a matter of economy, but also to give free passage for water through the wall.

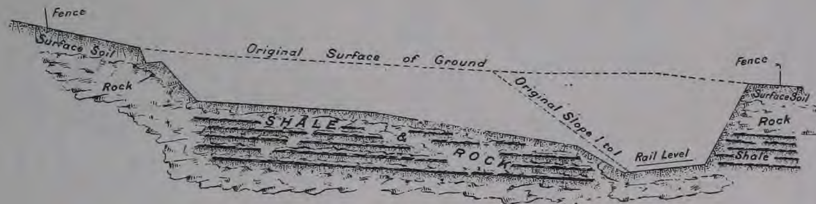
The slips so far mentioned are all brought about by causes which can be defined and dealt with more or less satisfactorily without difficulty. There is, however, a class of slip in cuttings which is much more difficult to cope with on account of the absence of all apparent cause; in fact, they are very common, and will often occur in a cutting on one side, whilst the other side will stand quite securely at a slope of 1 to 1.

As instances of this the writer can mention a cutting in Derbyshire about 60 feet deep, near the mouth of a tunnel, and another, also near a tunnel, in the neighbourhood of Sheffield, where signs of a slip occurred whilst the cutting was in progress.



TRANSVERSE SECTION

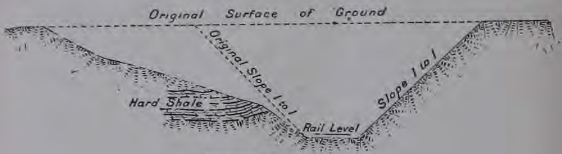
Fig. 3.



TRANSVERSE SECTION.

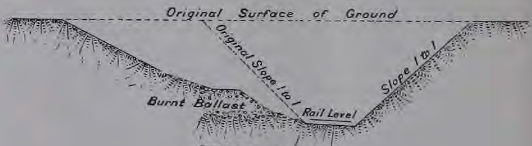
Fig. 4.

Figs. 5 and 6 show the cutting in the former case, with the slopes as first excavated in dotted lines, the full line indicating the slope as it had eventually to be got out, and it will be observed that the right hand slope has stood quite securely.



CROSS SECTION.

Fig. 5.



CROSS SECTION

Fig. 6.

The next figure (No. 7) shows the slopes in the second instance above given. As originally proposed, the slopes were $1\frac{1}{4}$ to 1 on both sides. When signs appeared showing that the ground was insecure, the slopes for the upper portion were flattened to $1\frac{1}{2}$ to 1, and stone counterforts built up the slopes in the form shewn upon the diagram, which is a very effective and usual preventative to stop slips which are not too deep-seated.

Trenches are cut 3, or even 4, feet deep up the face of the slope at suitable distances apart, and filled with dry rubble stone. Between these diagonal strips are cut and similarly filled.

Fig. 8 shows a slip which occurred quite suddenly about four years after the cutting was completed, and necessitated the working of a single line whilst the slipped material was being cleared away. To prevent a recurrence of this trouble or an extension of the slip the wall and drainage works shewn in the figure were constructed.

In slips of this kind no ordinary precautions, such as drainage, can be taken with any certainty of a satisfactory result, as in very few cases does the action of water appear answerable for the failure of the slope to stand, and a slip will frequently take place without any previous signs that the slope will not stand at the angle to which it has been worked.

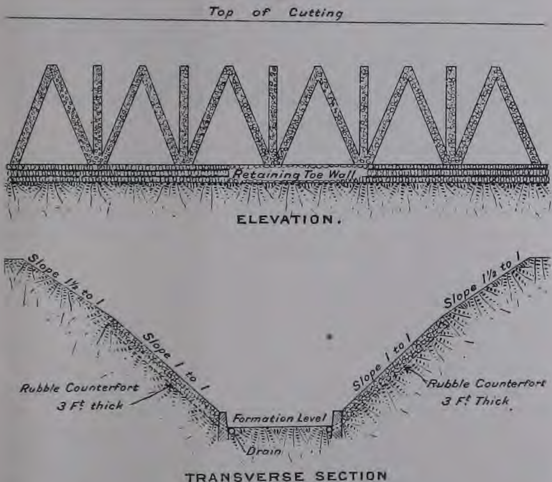


Fig. 7.

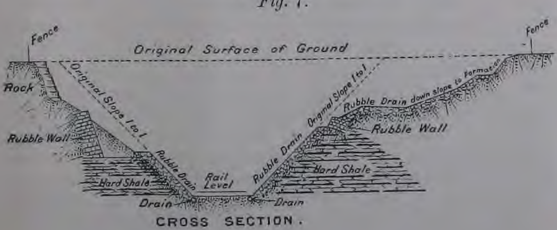


Fig. 8.

In the first case just mentioned many expedients were tried to stop the movement, such as dry stone counterforts and burning the materials which slipped down, which it was possible to do, as the clay was largely mixed with shale and bands of coal. Nothing, however, at a reasonable cost seemed to be effective, so that the slope was flattened to an angle at which it would rest without artificial support, as shewn in *Fig.* 5.

On a new line of the Great Western Railway, which is now being constructed, a slip of a very extensive character has occurred. The line is being constructed along the side of a hill, which for a considerable distance has slipped in, causing the removal of an enormous additional amount of excavation beyond what was anticipated when the contract was let.

Dry stone counterforts have been built to try and stop any further movement, which are similar to those illustrated by the figure lately referred to. The slip, however, continued to extend after these counterforts were built. Wide and deep cracks appeared in the hillside, into which the water during wet weather flowed, which greatly added to the movement.

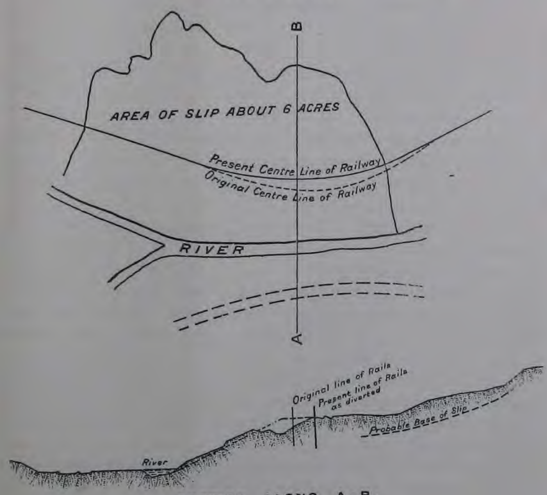
It may here be mentioned that wherever cracks appear in the ground above a cutting, steps should be at once taken to fill them in, so as to prevent the lodgment of water. The surface should be turfed and made as even as possible to allow of the rapid flow of the water over the surface.

In some countries, where the rainfall is excessive, slips are far more extensive and difficult to deal with than they are here.

In Jamaica, for instance, the annual expenditure upon the maintenance of the railway has been very large, chiefly owing to the small provision that had been made when the line was constructed against the probability of slips occurring on account of the exceedingly large rainfall, amounting, as it does in some parts, to as much as 200 inches per annum. In many instances the cuttings are converted into watercourses during a heavy downpour, and in one cutting the working of the line was lately stopped for nearly three weeks on account of the mass of material which slipped down from the slopes; and the writer is at present engaged considering the precautionary measures to be adopted to prevent further damage and a recurrence of these obstructions to the working of the line in future.

Figs. 9, 10, 11, and 12 will give some idea of the treacherous character of the ground through which this railway passes and the slips which have occurred during the last year.

Figs. 9, 10, 11.



SECTION ALONG A - B.

Fig. 12.

In cases of this kind (see figures as above) wide and deep concrete drains must be constructed along each side of the line, and drains enclosed in wide and deep counterforts constructed up the slopes and connected with the side drains, so as not only to get the water away quickly, but also to hold up the insecure material of the slopes.

Reference has so far only been made to slips in cuttings, but slips in embankments often give great trouble, and are difficult to stop when a movement has once taken place.

These slips are usually of two descriptions, namely:—(1) Where the material composing the embankment slips, and (2) where the surface of the ground upon which the embankment rests either slips away on the underlaying strata, or is so soft that it is ploughed up by the toe of the embankment, and offers no resistance to the vertical and lateral pressure.

Slips of the former description are generally not difficult to deal with, and can usually be arrested by flattening the slope to an angle at which the material will stand, and thus widening the base.

Slips in an embankment are often the result of different kinds of material having been tipped in varying thicknesses. This is frequently almost unavoidable in actual practice, as the excavation from, say, a rock cutting and a clay cutting may be proceeding simultaneously, both classes of material going into one embankment.

It is a curious fact that in high embankments composed of shale and hard clays from the coal measures the slope is seldom uniform for the whole height, the slope at the top and bottom generally standing at a considerably steeper angle than the central portion.

Slips in the material itself are rarely serious, and can usually be prevented extending by building counterforts up the slope and pitching the lower portion.

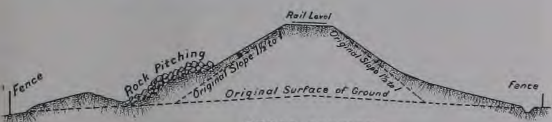
Figs. 13 and 14 give a section of a high and long embankment in Derbyshire on a railway recently constructed by the writer, and illustrate the pitching which effectually prevented any further movement in the slips which took place.

In the case of this embankment the precaution was taken of intersecting the site with a number of deep drains filled with stone, which greatly helped to prevent any serious slips; these drains are shewn on *Fig.* 18.

This is one of the most necessary precautions, and steps should always be taken to thoroughly drain the site of an embankment;

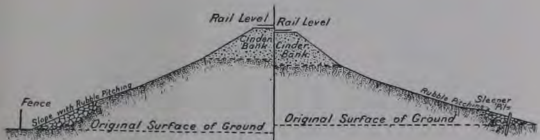
and many slips have taken place on account of omissions in respect of this essential detail.

Where, however, a slip is occasioned by reason of the seat of an embankment being either ploughed up in front of the toe or sliding bodily upon the underlaying strata, there is often great difficulty in stopping the movement.



CROSS SECTION

Fig. 13.



CROSS SECTIONS

Fig. 14.

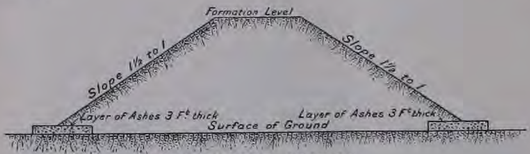
If there appears any chance of such a slip taking place, the best preventative is to cut a deep and wide trench along the line of the toe of the embankment, and fill up the trench with stone of as large a size as can conveniently be obtained. This trench should be taken down to the hard strata underlying the soft material upon which the embankment will rest. In some cases it is necessary to go down to 10 or 12 feet, which is, of course, a costly matter, and one which is sometimes postponed until it is too late to be effectually carried out.

Fig. 2 shows a toe wall of this description.

Another method sometimes adopted is to drive piles along the line of the toe, in order to pin the upper to the lower strata. This, however, is not always effective, as sometimes the toe of the embankment will lift the ground in front bodily upwards, taking the piles with it.

Plate III. shows a cross section of a slip which it was attempted to arrest by this means; most of the piles in this instance were entirely destroyed, and some of which, as will be observed, are now 10 or 12 feet above their original level, the natural surface of the ground having been forced upwards by the weight of the tipped material. This slip continued to move for about two years, and the proper level of the formation had to be maintained by the deposit of many thousands of tons of ashes, as shewn upon the diagram.

Where the nature of the ground makes it probable that small slips of an unimportant, but perhaps troublesome, character may occur, a very good and generally inexpensive preventative is to deposit a layer of ashes about 3 feet thick and 8 or 10 feet wide along the line of the toe to form a "cushion" (see diagram No. 15).



TRANSVERSE SECTION

Fig. 15.

As before stated, it is often impossible to form any certain opinion as to the likelihood of slips occurring in any particular cutting or embankment; but since the introduction of steam "navvies" for the purpose of forming the excavation, it has become the general practice to take out the excavation in layers (or "lifts" as they are technically termed) of from 15 to 20 feet deep, which minimizes the probability of slips occurring.

As the excavation proceeds the slopes should always be trimmed back to the required angle, so as to reduce the superincumbent weight as much as possible, as by this means the risk of any movement is considerably reduced.

Fig. 16 shows a longitudinal section of a cutting got out in this manner.

In forming embankments this system of constructing by "lifts," or different levels, is still more important, as the lower portion forms a platform, which may become consolidated before the next layer is tipped upon it. It also avoids bringing the whole weight of the embankment at once upon the surface of the ground.

LONGITUDINAL SECTION OF CUTTING
SHOWING EXCAVATION IN "LIFTS"

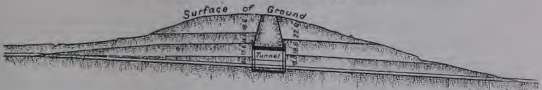


Fig. 16.

Fig. 17 shows a long and high embankment tipped in this manner.

LONGITUDINAL SECTION OF EMBANKMENT
SHOWING TIPPING IN "LIFTS".

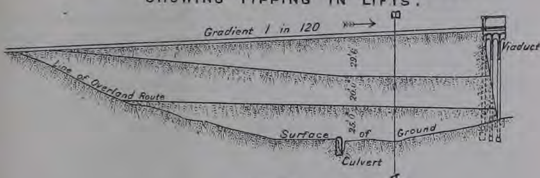


Fig. 17.

The bottom layer was formed by running the tip wagons from the cutting along what is called the "overland route," laid upon the natural surface of the ground to the proposed level, and when the whole width of the embankment at this level had been completed the next layer was tipped upon it. *Fig.* 18 shows the cross section.

CROSS SECTION A.B.

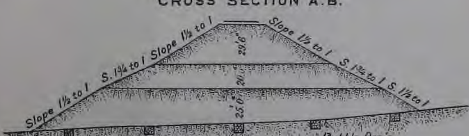


Fig. 18.

In the case of the particular instance shewn in the figure, the top was brought from the opposite direction as the line rose with a gradient of 1 in 120. Contractors always arrange, if possible, to tip down hill. The figure shows this.

Not only is considerable trouble and expense caused by the slips of themselves, but it often occurs that these slips do great damage to structures in the immediate neighbourhood.

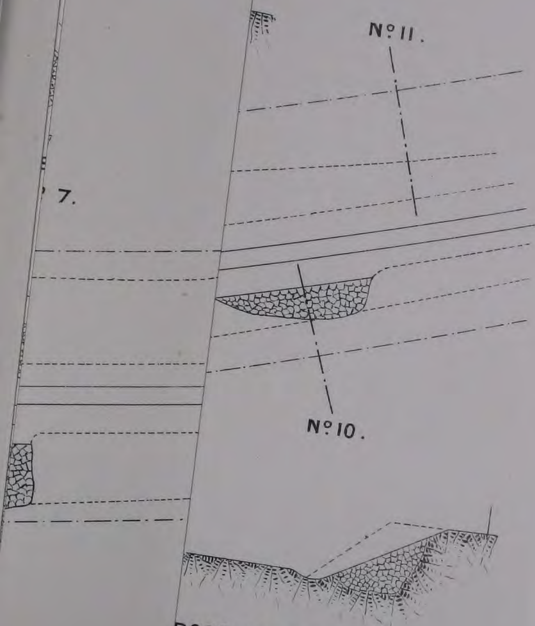
If a slip occurs at or near the site of a culvert, very great damage and trouble may result, as it frequently happens in cases of this kind that the culvert is torn asunder and the flow of the stream thereby stopped, which, of course, adds to the magnitude of the slip.

The writer has known cases where this has occurred, which necessitated the driving of a tunnel under the embankment to enable the culvert to be repaired.

It is therefore of the greatest importance that the foundations of all culverts and bridges in deep embankments should be carried down to a solid strata, and so as to be below the action of any possible surface slip. Care in this respect is also very necessary in the construction of the wing walls of bridges in embankments, as they always feel the first effects of any movement.

The writer has not attempted to deal with the subject of "land-slides," which are fortunately of comparatively rare occurrence, and must be dealt with as circumstances suggest, it being impossible to lay down any rule.

PLATE I.



ROSS SECTION N° 10

PAPER VI.

AMERICAN BRIDGE TYPES.

By F. E. Robertson, Esq., C.I.E., M. Ins. C.E.

(Lecture delivered at the S.M.E.).

The subject which has been suggested for discussion this afternoon is American Bridge Types, and our examination of it will be directed to ascertaining wherein the ordinary American practice in the design construction, and erection of bridges differs from the English, specially with reference to speed in construction and erection.

Your interest as military engineers lies not so much in the abstract theory of bridge design, on which there are plenty of text-books, as in the purely practical consideration of what is the best type and method for rapid construction and erection. You may not be called upon to design girders, but you may very likely have to erect them, and should, therefore, be in a position to choose such types of girders and modes of erection as experience has approved. The subject is one which has been a good deal before you lately in connection with the Atbara Bridge, and with the replacement of bridges destroyed in the war in South Africa, and is one of the greatest importance in modern warfare. The destruction of a bridge in olden days was only serious in the case of an unfordable river, and until a pontoon bridge could be thrown across, but the destruction of a bridge on a railway, even over a dry ravine, means the loss of the services of the railway beyond that point until communication has been restored, and those who have had to contend with this difficulty know too well what it means. I may remark, in passing, that where rolling stock is available on both sides of a break, a good deal of work can be done by a wire rope aerial tramway and carriers of the simplest construction pulled backwards and forwards by a light line. Such cableways have been used for spans up to 3,000 feet and loads up to 30 cwt., but the possible combination of span and load depends upon the strength of the available ropes. Generally the loads are from 10 to 15 cwt., and the capacity of such a line varies from 12 to 30 tons per hour. But to return to our proper subject. There is probably a general impression, due to the frequent bridge accidents reported in the papers, that American bridges are rather ricketty structures. There is a certain amount of truth in this idea, as there are bridges and bridges in America, but it is to one class only of these bridges that the accidents can be attributed. The bridges built by the well-known bridge companies are inferior to none in the world in design and workmanship, the men in technical charge of these works being specialists in their knowledge of all that pertains to bridge work. The discussions in the American Society of Civil Engineers also often turn upon disputed points in bridge design, which are thrashed out with much more keenness than such discussions generally raise in England.

But there are in America numerous so-called bridge companies, the staff of which are mere country blacksmiths, utterly ignorant of the theory and careless of the practice of bridge construction. Details of their structures are from time to time given in the American technical journals, either in reporting an accident or warning against one in the case where an engineer happens to have seen the bridge while still standing. Such a bridge sometimes stands for some time, either from mere force of habit or because the working load does not happen to have passed over it. It is this class of bridges, bought by Local Boards of country farmers, who consider the employment of an engineer a sinful waste of money, which has given American bridges a bad name in the mind of the public; but we take no further notice of it, being abnormal, while our subject is the consideration of the typical American railway bridge designed by very competent engineers, from whom we shall probably learn something.

I should add also on the accident question that most of the American railroads possess many miles of wooden trestles put up at the time of first construction as the quickest means of getting across a valley, with the intention of filling them in by a bank when funds permit. Many recorded bridge accidents are caused by these trestles catching fire, and there are a few cases on record where they have failed from want of longitudinal bracing; but these again are cases where the trestle has been put up in a hurry by a force of carpenters, without a design or engineering supervision.

Having now cleared the ground by defining with what American bridges we are concerned, let us examine the specific differences between them and the structures designed for similar purposes in England. It becomes more difficult every day to classify these differences, as the practice in either country continually tends to approach that of the other. We are leaning towards the more economical proportions of American design, while American practice is now adopting the more substantial detail which used to characterize English practice. Only a few years ago it would have been difficult to find a plate girder of more than 50 feet span in America, while now 100 feet is reckoned as their superior limit; and I saw not long ago in an American technical journal the details of the transportation of a 110-foot plate girder in one piece from the shops where it was built to its final destination. It may thus be said that up to about 100 feet there is no practical difference between England and America, and even the heavy trough flooring used with plate girders in this country is being rapidly introduced in America. It is just between 70 feet and 100 feet that one feels in doubt whether to use a plate girder or a riveted truss, and local circumstances generally decide the question. In earlier days, also, there was not much difference between the two countries, as both used pin-connected pony trusses for spans as small as 50 feet. I should perhaps explain that a pony truss means a through bridge, whose girders do not reach up high enough to admit of overhead bracing. There were miles of these bridges in India, but they are being rapidly replaced by plate girders. These small pin-connected girders are quite out of favour in both countries, and for the next size above plate girders riveted trusses are used. In England the latter are used up to any span, and the best American practice now adopts them for all spans up to about 120 feet, and some engineers go as far as 200 feet. So far then as spans up to about 150 feet to 200 feet are concerned, there is practically no difference between England and America in the choice of type, though the proportions of the girders are not quite the same, a point to be dealt with hereafter.

Above 150, or a little more, we have a divergence, the Americans invariably using pin joints, while English and Continental engineers adhere to riveted joints; and this holds good up to the largest spans yet constructed.

After differences in type of bridge, we next consider differences in the comparative anatomy of the girders, that is to say, in the outline of the girder, proportion of depth to span, and number and size of panels. There is not much scope for difference in the plate girders, though perhaps on the whole they are made slightly deeper in America than in England. The most economical proportion of any girder with parallel chords is perfectly definite; it is when the weight of the web equals that of the chord. With large spans other considerations prevent the best theoretical depth being used, but the formula may be worked to in plate girders. In trusses of all sizes there is a well-marked difference between America and England. The practice in America is very well defined, and may be summed up in the following characteristics:—Depth about $\frac{1}{5}$ span at 100 feet to $\frac{1}{6}$ at 200 feet and above, with a slight further reduction in the case of very long spans, as the great depth which this ratio would require would offer some difficulties in erection, and make the traveller very expensive, and, further, would lead to difficulties with the wind strains unless the bridge were made of a great width, when the economy in the trusses would be swallowed up in the floor. Again, as to general anatomy, the almost universal type is the Pratt truss, or N truss with parallel chords for all ordinary spans, the panels being few and long, the limit of panel length being that which will not make the angle of the main and lateral braces too flat. Multiple intersection trusses are hardly ever used now in America, though some large ones have been built.

It is a great deal more difficult to say what is the English or European practice, as the taste of individual designers differs so much, but it is a fair general description to say that the truss depth varies from $\frac{1}{8}$ to $\frac{1}{10}$ or even less, that the panels are kept quite short, and multiple intersections are in favour. Lattice girders—those in which the web members all lie at 45°—are a good deal used in Europe but rarely in America. *Fig.* 1 gives in full lines the average profile of an English truss of 150 feet span, and in dotted lines the American equivalent. The

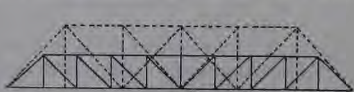


Fig. 1.

difference in the depth and number of members is very marked. *Fig.* 2 gives in full lines the profile of a 200-foot span bridge lately designed for India by our firm, and the corresponding American average in dotted lines. Here the difference is not so marked as in the first case, and it will be interesting to note that, comparing the span shown in *Fig.* 2 with an older 200 feet span on the same railway of the proportions shewn in *Fig.* 1, I found that using the same unit stresses, the new span with a heavier load, in the shape of a ballasted floor, weighed 35 tons less than the old one.

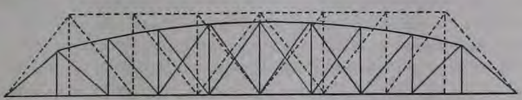


Fig. 2.

When we come to long spans, 400 feet or 500 feet, we have still no difficulty in presenting an American type, but we have considerable difficulty in knowing what to present as the English or European type, partly because there are so few bridges of that size, and partly because no two of them are alike. I may recall to you in *Fig.* 3, which shows in full lines the outline of half the Saltash Bridge of 455 feet span, that the Americans did not invent nor have they a monopoly of deep

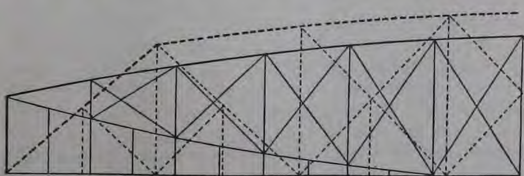


Fig. 3.

girders and long panels. The genius of the great Brunel recognized, even at that early period of bridge building when the Saltash Bridge was erected, the importance of these two points, and this and the Chepstow Bridge are far in advance of bridges built not only at the same time, but at a much later date. The double parabolic girder has always been a favourite on the Continent, but the panels in their bridges are much shorter than they are in Brunel's. The top chord of this bridge is an oval tube the whole width of the bridge; the bottom chord, the braces, and floor suspenders are links. The dotted lines show how the problem would be treated in America. This form of truss is known as the Petit, and you will observe that the principle of long panels is adhered to for the main members, but as the stringers would be too long to be economical, sub-panels are introduced. I should also point out that in actual practice the sub-posts are carried up so as to halve the unsupported length of the top chord segments, and horizontal struts in every other panel halve the length of the posts figured for bending. These are not essential members, and have, therefore, been omitted from the diagram for the sake of clearness. The question to decide in any case is whether the metal in the secondary member is less than that saved in the main member by its use.

As a contrast to the last figure and a typical illustration of Continental practice, *Fig.* 4 exhibits in full lines the outline of half the Kuilenberg Bridge over the Lek in Holland of 492 feet span,

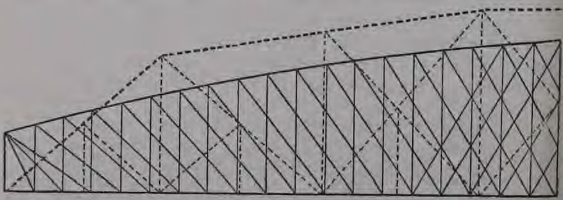


Fig. 4.

one of the largest trusses in Europe; also with the American treatment of the span shown in dotted lines. Here the difference between the American and the European idea is quite as marked as it is in *Fig.* 1, and the reason for the superior economy of the American design is not far to seek. You would find in the first place if you figured it out that the greater depth of the American type gave a more economical distribution between web and chords than did the other, and you can clearly see on the diagram the economy resulting from long panels and few members. With many web members the economical depth is diminished, since the proportion of weight in a foot high of the web is increased. It is also very clear that you cannot build three posts as economically as one, to carry the same load, for most of the metal in a post goes in making it stiff enough to carry itself; and you have besides the irreducible practical minimum of thickness in a piece to deal with three times over instead of once. Even with tension members the practical designer recognizes that there are limits of unsupported length, which should not be exceeded in order to secure a structure of adequate rigidity, so that even with this class of member one stout one is more economical than three of equal merit to carry the same load. A good deal of the weight of a girder also is in superfluous but unavoidable material at the joints, so that a diminution in their number makes for economy in weight as well as in time of erection. The American designs generally may be taken as necessarily the most economical possible when the circumstances under which they have been evolved are considered, viz., keen competition for a bridge of a given strength to be built for a lump sum, the design of the bridge, subject to the limitations of strength given in the specification, being left absolutely open. This system in the hands of able men who spend their lives at the study, assisted by copious discussion in the technical societies and journals, must necessarily obtain the best results possible. In England, on the contrary, the actual builders of the bridges rarely if ever design them, but tender on designs made by the engineers of the buyers, each of whom has his own ideas, and though he does his best for his clients, has not the imminent spur of necessity to produce the most economical design possible, but puts solidity first. In some cases this feature is important, and the American designers are now giving more attention to it.

Nor do the various conditions which should govern the design of a bridge seem to meet with that attention and discussion in England which they receive in America. In short, the building of bridges is far more highly organized in America than it is in England. A striking instance of this is to be found in the fact that while about half a dozen of the American steel works issued pocket-books of their sections, with all the tables that a draughtsman could want to help him in getting out a bridge or roof design, there was not until lately a single one to be got in England, and I do not at this moment know of one at all comparable to the American ones. The English steel maker says, "I roll plates and shapes that are ordered from me." The American says, "I roll them to build into bridges and other metal structures. I must have this information in order to get out my own designs quickly and well. If I publish it with my sections, people who are designing ironwork will require this information, will design to my sections, and will naturally come to me to build for them."

It is worthy of remark also that while American engineers have arrived at an absolute consensus of opinion upon the most suitable type in all its leading features, you do not find the same consensus of opinion in Europe. Not only do different engineers differ in their ideas, but the same man will vary the design of his girders, and all those designs cannot be the best. Nor is there any suspicion that the Americans have fallen into a groove without reflection ; the keen competition in bridge building would soon evolve an improvement on present types, were such an advance possible.

This seems the proper place in which to note the remarkable divergence of opinion between American and European, especially Continental, practice in the matter of continuous girders. Indeterminate systems, or, rather, systems in which the distribution of stress depends upon the relative elasticity of the members, are absolutely ruled out in American practice, and are explicitly condemned in some of the best text-books, which at the same time give full instruction in them as a mathematical exercise. It is not from want of study that American engineers reject statically indeterminate structures, for some of the clearest investigations of this somewhat intricate subject have been written by Americans. But they claim that with the best proportions for both, the continuous girder is not so superior to the simple girder in economy as to balance its disadvantages, and principally they object that the whole distribution of stress depends upon the fit of the members, and may be very different from the calculated amounts. A Continental engineer would certainly prefer continuous girders for spans of 200 feet, while an American engineer would use detached spans up to about 500 feet, unless for reasons connected with erection he used cantilevers. The fact seems to be that, with the shallow trusses used in Europe, continuity does produce much greater economy than it would if applied to the better-proportioned American truss. The above remarks refer to trusses, but arches have to be considered in this connection. Here opinion is not so decided ; the two-centred arch seems on the whole to be favoured in Europe, while in America we have at least one arch without hinges, the well-known Eads Bridge of 520 feet spans over the Mississippi at St. Louis, and some two-centred ones. It has lately been contended by able writers in America that the small economy—from 3 per cent. to 5 per cent.—of the two-hinged over the three-hinged arch is quite counter balanced by the extra metal required for temperature stresses in the former, and the probable unequal distribution of stress at the moment of closing is also objected to. It must, I think, be admitted that the continuous structure is more rigid than the discontinuous, such as a cantilever or a three-hinged arch. On the whole we cannot say that the question of continuity in arches has yet received any positive answer in America.

We shall have occasion to refer again to continuous girders when we come to speak of erection.

Beyond about 500 feet we enter the region of special spans, and here any discussion on comparative types is hardly practicable for want of sufficient examples. In England we have only one long span bridge, the Forth, and that is a very long and very special span. We have in India the Sukkur Bridge of 820 feet span, also a cantilever of a special type and the bridge over the Hooghly at the village of that name near Calcutta, a 520-foot cantilever of ordinary girders. On the Continent we have several two-centred arches of from 500 feet to 600 feet span, whose conditions were obviously dictated by the gorges which they span. In America we have for comparison a considerable number of cantilever bridges up to 800 feet span and some large arches. In crossing the big rivers, where headway is an object, the cantilever is the ordinary type, and its outline in many cases is simply that of an ordinary girder with parallel chords, but sometimes the depth over the piers is slightly increased. We have, however, no special type of cantilever, as distinct from the ordinary truss, yet developed in America as it has been in the case of the Forth and the Sukkur Bridges. The arch seems coming more into favour in America where the site indicates its employment, and the Niagara gorge is an example. The first railway bridge over that river was a stiffened suspension bridge, the next a cantilever, and the latest a two-centred arch of 550 feet span. There is also a road and electric railway arch-bridge of 840 feet span. The Eads arch at St. Louis, of which I spoke, deserves particular mention as one of the earliest of the long span bridges and a very original structure, quite opposed to ordinary American practice. It is not a type which is likely to be repeated. The ribs are hingeless, made of two built-up steel tubes connected by bracing; they were erected by building out, and the greatest trouble was experienced in closing them at the middle. Some failed to close altogether, though packed in ice throughout their length to induce contraction, and a special key piece had to be used. This was cut with a right and a left-handed screw like a coupling, and screwed up after being inserted.

There is yet a class of long span bridge to be found in America which is not represented in Europe, the railway suspension bridge with wire cables. The oldest and best known of these was Roeblings Bridge of 820 feet span over the Niagara River, which has just been superseded after 25 years service by the new bridge spoken of above. This bridge had wire cables and a deep wooden stiffening truss, replaced after some years by one of metal without stopping the traffic, a very creditable feat of engineering. There is also the well-known Brooklyn Bridge of 1,600 feet span, which, though it is not actually a railway bridge, carries several tracks of cable and electric cars, which have on occasions completely covered the bridge. Then there is the new East River Bridge of about the same span now under construction. This will be 118 feet wide, and will carry 2 railway and 4 trolley tracks, and we have the Hudson River Bridge of 3,100 feet span, designed to carry 6 railway tracks, which when built will be the premier bridge of the world. There is a future before the stiffened suspension type for very long spans.

After the general outline of the bridges, the next point which presents itself for examination is the consideration of permissible unit stresses. This is a very interesting and important part of bridge design, and has been copiously discussed on the Continent, in India, in America, everywhere, in fact, except in England. On the Continent the matter is, of course, settled by authoritative Government decree as to the loads for which bridges must be designed and the permissible stresses for the different sizes of bridge, so that the practice is very well defined. In America there is no central authority which occupies itself with such matters, and each bridge works or chief engineer has his own specification. These, however, as a result of much discussion, do not differ very widely, the variations being mostly in detail, as, for instance, whether actual wheel loads or the nearest equivalent shall be used in calculation, and what shall be the exact form of the coefficient to be applied to allow for the effect of live load. It may fairly be said on the whole that practice in this particular does not differ more between countries than it does between individuals of the same country.

After noting the difference between England and America in the general types prevailing in the different sizes of span and the comparative anatomy of those types, we shall proceed to discuss characteristic differences in details, those details I mean which lead you at once to conclude that the bridge in which they were present was undoubtedly of American or of English origin.

In plate girders there is not much room for difference in details, and I know of but one characteristic American feature, which is exhibited in *Fig.* 5, and is very characteristic indeed of the differences of thought between the two countries. The left-hand side of this figure represents a cross section of the ordinary English plate girder, with which you will all be perfectly familiar, while the

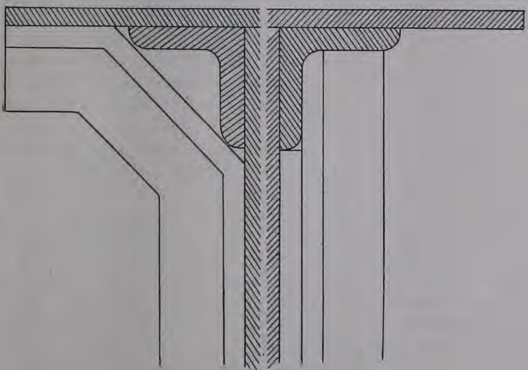


Fig. 5.

right side represents the American practice. There are two points of difference. In the English girder the stiffeners are cranked and riveted with a couple of rivets to the flange plate. The edges of the web plate are planed, and are a dead fit with the back of the angles against the flange plate.

The Americans laugh at the idea of cranking the stiffeners, and carry them straight up—as shown in the diagram—with a filler the thickness of the angle, or sometimes crimp them over the angles. They use universal plates for the web, that is, plates with rolled edges, and set them just below the backs of the angles so that there is no difficulty about the fit. You will never find the Americans putting any finish into work unless there is a definite object to be gained.

In large trusses we have, of course, the characteristic American pin joint, generally combined with tension members of eye bars. I may remark that the new Niagara arch has all joints riveted. It is, therefore, in the riveted trusses of moderate span that we should principally look for typical differences of detail between American and English practice. Detail is so very much a matter of personal taste that greater differences may be found between the bridges in one country than between the typical bridges of two countries. I should have said not long ago that stiffening purely tension members was a typical difference of English from American work were it not for the fact that I have seen details of some recent American bridges, which go even further in the direction of stiffening members always in tension than would most English engineers; and this leaves me in doubt as to what can now be called typical differences, and how long they will remain so.

In England it is usual to provide splices in compression members capable of taking up the full stress to be transmitted, no matter how well the joints are butted. In America, on the contrary, they content themselves with furnishing adequate splices to keep the pieces in line, but depend upon the butted ends to transmit the direct thrust; and I know of nothing in practice to lead us to suppose that this detail is not quite satisfactory. Even this difference is not absolute, as the older East Indian Railway bridges, built in quite the early days of railroading, had splices after the American style. The use of lacing, or connecting the sides of a member by a single or double lattice of small bars, is universal in America, while English engineers prefer plates. The typical post of an American bridge is two channels set in the plane of the bridge and connected by lacing, while the ordinary type in England is a built joist set with the web across the plane of the bridge. Adjustable counters may be reckoned a purely American feature, never being found in European work. The floor system also usually differs very much in America from what is required in Europe. Even in very important bridges the Americans are content with simple cross sleepers, or ties, as they are called, placed on the stringers with a guard timber in case of derailment, and a metal floor in such cases is almost unheard of. In Europe, on the contrary, and even in India, a complete metal deck is generally considered as necessary for all but the most unimportant structures, and some engineers ask for metal decks even with 40-foot girders. This makes an enormous difference in the weight to be carried, the dead weight of floor in some European examples being over six times what is found sufficient for similar structures in America. For small spans and heavy traffic, as on suburban lines, solid trough flooring is just as much used now in America as it would be in similar circumstances in Europe.

The lateral bracing systems have always received particular attention in America, as is indeed obligatory from the light character of the structures and the absence of any floor, which in English bridges often takes the place of the lower laterals, while heavy overhead arches are substituted for the upper lateral system. I have indeed seen English-built bridges of an old type with neither solid floor nor lateral system, in which, therefore, the resistance of the bridge in a horizontal direction against wind and vibration depended upon the lateral strength of the girders considered as a beam.

After discussing differences in design, the next division of the subject which presents itself is shop practice, the standard of which, by the aid of powerful machinery and improvements in steel making, has been gradually improving in all countries. At the very beginning of shop practice we should cast a glance at the raw material. Steel, as a material for bridges, was later in establishing itself in America than in England; now it is the only material, and perhaps a few words on this point may not be amiss, as the differences between the various kinds of structural steel are not always fully appreciated even by those who have a good deal to do with it. There are two main processes, the Bessemer and the Open-hearth (or Siemens-Martin), and each has two divisions, the acid and the basic. I expect you all know what a Bessemer converter is, and many of you will have seen it at work. The molten metal is run into this vessel, and air is blown through it; the oxygen in the air combines with the carbon, etc., and burns them up. When they are burned out, a little more carbon is added to give the required quality of steel, and the charge is poured into ingots. This is very roughly, for we have not time to enter into details, the outline of the process. The terms "acid" and "basic" refer to the lining of the furnace, the former being silicious, as ordinary firebrick, and the latter calcined magnesian limestone. Phosphorus is the impurity which has the worst effect, and if you have an ore containing very little of it you can make good steel in the acid furnace, but if the ore contains much phosphorus you cannot, because you cannot burn out the phosphorus unless there is a slag with a basic reaction with which the phosphoric acid can combine, and when you have a basic slag it will attack the acid lining of the furnace and melt it. If, therefore, you desire to get rid of the phosphorus you must have a basic lining; and, further, you must in the Bessemer process use a pig rich in phosphorus in order to keep up the heat, and the trouble then is to know just when the right amount of phosphorus has been burned out. As a Bessemer blow only takes about 8 or 10 minutes, you have no time to take samples and analyze them.

In the Siemens-Martin process, on the contrary, the steel under conversion stews for hours in a reverberatory furnace, and you can take samples and pour off the charge only when it meets requirements. The same varieties of acid and basic furnaces are run as with the Bessemer process, with this difference, that since the heat is furnished from an external source, viz., the fuel, it is not necessary to have a highly phosphoric ore, and you need not, therefore, run any risk of too much phosphorus, which means a brittle steel. You will see from this rapid sketch of the different processes that while as good steel *may* be made in one as in the other, there is considerable risk with the Bessemer process, particularly the basic, of getting what is not desirable. Basic Bessemer is used in England and largely on the Continent for structural purposes, but it is not a material to be trusted, of which I will presently give you an example.

In America the only steel used for bridge work is Open-hearth, generally basic. They recognize three qualities, soft, medium, and high, of which the tensile strength is—soft, 22·2—26·8 tons per square inch; medium, 26·8—31·2; and high, 31·2—35·8, the medium quality being generally used, and corresponding very closely to the average English requirements for bridge plates. They allow 0·06 of phosphorus for acid and 0·04 for basic steel, which is not far from English practice, where the chemistry of the steel is prescribed in the specification.

One can hardly say that there is any very marked difference between the average English and American plant of a bridge works. The Americans to a small extent use special machines, such as the punch for forming and punching lacing bars at one operation, and a few multiple punching machines are used, but not enough to make special machinery a feature in a bridge building yard. The construction of bridges, however much they may be standardized, is not a work which lends itself readily to special machinery, or you may be sure it would be so dealt with in America. One feature in American shops is very marked as against the English, viz., the quantity of work done under cover. In America they have sheds sufficient for their work, and you do not hear the excuse so often put forward in England for delay—that the work was stopped on account of bad weather. This again is led up to by a difference in procedure. An American bridge yard does not require so much space as an English one, because they never dream of putting a whole bridge together, while in England it is almost universal. This is, of course, to ensure a good fit, but I can give one curious instance to the contrary. A 230-foot span once came into my hands to erect in India, in which the rivet holes had been mangled in the most extraordinary way, cut out in a series of scallops, and the funny thing was that there appeared to be no reason for this, as the original holes came in perfectly. An investigation showed clearly that the original holes as turned out from the shop were all right, but that the girders had been put together hastily and badly in the erecting yard, and the holes hacked away instead of being matched properly. In this particular instance the work would actually have been better not erected.

Erecting girders means a good deal of work, especially with large spans, and is dependent on the weather, rather a fatal thing in England in the winter. A 300-foot span will require the services of two Goliath cranes of the largest size and an army of labourers and platers for a month to erect and another fortnight to dismantle. But it is difficult to see how to avoid this trouble when the maker of the bridge has not also to erect it at site.

I should say that the drawing offices were stronger in America than in England, that the templet work is much about the same, and the punching not quite so good as you can get done in England with nipple punches.

A difference is to be found between English and American practice in the amount of punching allowed. In England it is considered preferable to drill out of the solid, or if sub-punching (which means punching a small hole and then drilling it out to the required size) is permitted, it is required that at least $\frac{1}{8}$ inch all round the punched hole must be drilled out, and the same amount planed off a sheared edge. In America, on the contrary, the merest skimming of the holes is generally considered sufficient, if indeed the reamer is used at all. Opinion on this point is very varied, and is now tending somewhat to the English view. One prominent American bridge engineer now specifies that the punch must be $\frac{1}{8}$ inch less in diameter than the rivet, and that the hole must then be drilled out by a twist drill to $\frac{1}{16}$ inch larger diameter. He, however, in a discussion on the subject, stated that his reason for reaming was rather to obtain good clean holes than from any fear of cracks starting from a punched hole. It is, indeed, true that the bulk of the American structural steel is much softer than the average of ours, so that it will not do to assume that what is necessary in England is equally so in America; but to show you that the danger of cracks starting from punched holes is not imaginary, I will direct your attention to *Fig.* 6, which represents the fracture of the upper chord of the swing span of the Embabeh Bridge over the Nile at Cairo. The

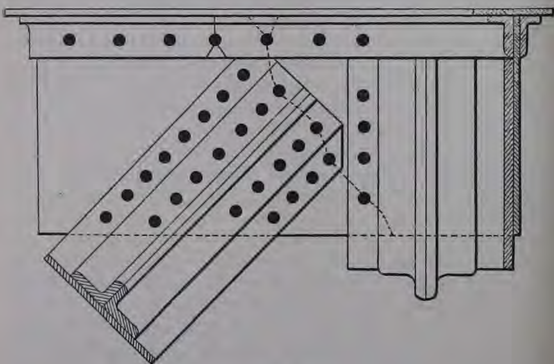


Fig. 6.

upper chord was found torn across in the way you see, and a month after the repairs had been effected the chord of the other girder tore in a precisely similar manner. Now these girders were built by a French firm, who used basic Bessemer steel, a most untrustworthy metal, and they were permitted to punch the holes, with the result that you see. The percentage of elongation of the material under test varied from 4 per cent. to 26, and the analysis was bad. The effect of the punch in hardening the metal is very well illustrated by the phenomenon shown in *Fig.* 7, where you see how a rack coming towards the hole turns off where it meets the hardened ring of metal round the hole until it finds its way, presumably through an incipient crack, into the hole, which it leaves on the opposite side by a clean cut, starting also on another incipient crack.

Fig. 7.

To sum up the comparison between English and American bridge shops, we may say that the enormous output of the latter (the Pencoyd works which built the Atbara Bridge can do 70,000 tons a year) is due principally to the following conditions :—

1. They roll their own material.
2. Temporary erection is saved.
3. Designs all follow the same general character, and no smith's work nor fitting which is not absolutely necessary is used.
4. Shops are more commodious, being expressly designed for the purpose, while many of the English shops have grown up anyhow.

Rolling their own material is an enormous advantage ; the stuff comes in regularly, and proper arrangements can be made. An English builder who has to depend upon an outside mill never knows where he is, and the disorganization and expense caused by the non-arrival of material are so great that it is now usual to do nothing to a span until all the material has been actually delivered by the steel maker.

From shop work we naturally proceed to erection, which is, I fancy, the part of the subject which interests you most. In this there are not any necessary or prominent differences where the type of the girders is the same, and in the case of large pin-connected girders, putting in pins instead of driving rivets is the principal difference, and gives the American girder a slight advantage in point of speed. Such very large spans, however, would seldom fall within the scope of the military engineer's duties, and we shall more profitably consider the case of moderate spans, say, of 100 feet to 150 feet.

First of all it will no doubt be useful to you to have a list of the tools you will require. Here it is, supposing your gang to be about 30 men; of course, if you can get more men and tools, so much the better :—

4 sets each of 8-inch and 10-inch double blocks.
2 10-inch single blocks.
4 10-inch snatch blocks.
4 1-inch lines, 200 feet long.
4 $\frac{3}{4}$-inch lines, 200 feet long.
6 1-inch lines, 50 feet long.
20 lashings, 30 feet.
8 rope slings.
1 dozen drifts.
1 forge and set riveting tools.
$\frac{1}{2}$-dozen snaps for each size of rivet.
A good supply of service bolts and washers.
4 crab winches.
1 axe.
1 cross-cut saw.
1 hand saw.
4 $\frac{7}{8}$-inch augers.
8 crowbars.
4 8-lb. sledges.
3 flat chisels.
3 round-nose chisels.
3 cold sets.
2 chipping hammers.
2 jacks.
2 spanners for each size of bolt.
2 monkey wrenches.

I would strongly recommend everyone who has erection of a pressing nature to do, to order with the material or get made a lot of cotter bolts, as shewn in *Fig.* 8, of the sizes of the rivets to be used. A joint made up with from a quarter to a third of the holes filled by service bolts and the rest by these is every bit as good as a riveted joint, and when opportunity offers they can be changed one by one for rivets. They should not be knocked in too hard, a light hand hammer is sufficient. I have used these on a temporary 200-foot span, on which was erected the central span of the Sukkur Bridge, and they gave complete satisfaction; and when the temporary span was taken down the holes were absolutely uninjured, and the span was afterwards utilised as a road bridge.

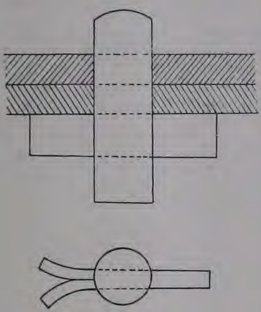


Fig. 8.

In most cases a girder has to be erected on a staging of trestles or piles; these are pitched about 20 feet centres, and spanned by other timbers, upon which the girder is erected and the traveller runs. *Figs.* 9 and 10 give an idea of such a traveller in cross section and in elevation.

The traveller is supposed to be 25 feet or a panel long, it is easily made of timber, and runs on small cast-iron wheels. With a traveller of this shape you put a winch over each panel point on each side, or four in all, so that you work at two posts at once, and take up a chord piece by each end; but I have also used much shorter travellers, with wheel base only long enough for stability and the top only wide enough for a tranverse run-way for a small lorry carrying a winch, one for each side. With a traveller of this shape you generally use two which can work independently at light pieces or together at heavy ones. The top of the staging should be a clear foot below the bottom of the girder to allow of the latter being supported on folding wedges or other such contrivance for lowering any point of the girder to get it to the proper shape. The wedges should be placed under or as near to the panel points as possible, and the piles or bents of the staging should also be so spaced. Remember that you can let a girder down on the blocks easily enough, but you cannot easily raise it. Keep the camber, therefore, always a little full until you have closed the girder, and then let it down exactly right before finishing the joints. Of course, you *can*

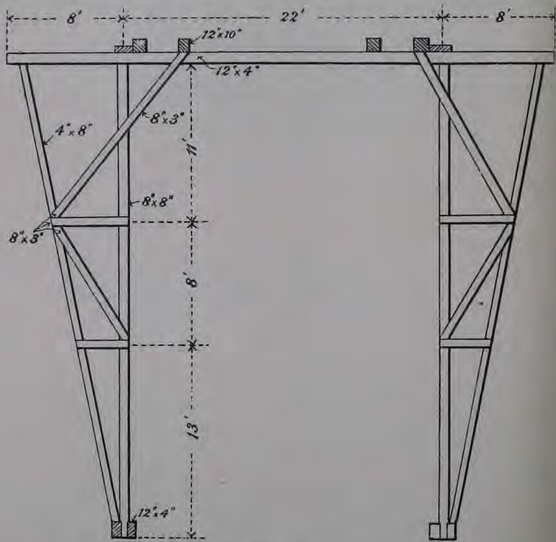


Fig. 9.

erect a girder with a derrick pole without the aid of a traveller, but the latter is such a convenience that it is always worth while to make it if more than one span has to be erected. Some sort of wheels can always be found or made on a railway, and rough timber is all that is wanted. The traveller is easily erected and dismantled by the aid of a sleeper stack, when it can be sent on to the next place.

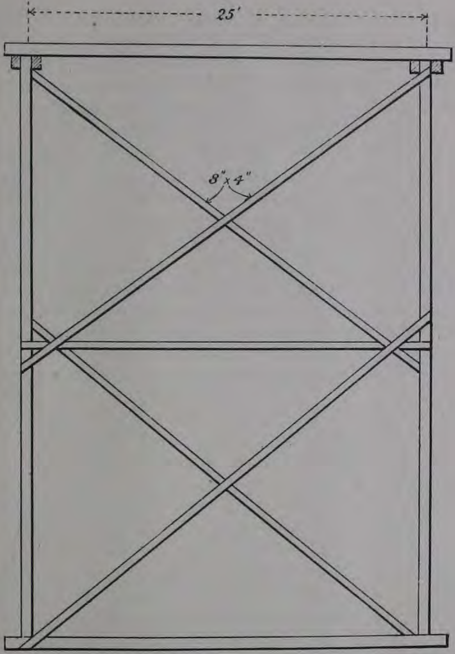


Fig. 10.

The mention of a sleeper stack reminds me to warn you of the danger of fire when using them, or, indeed, any sort of wood staging. Buckets of sand and of water should be kept ready, and special fire watchmen told off. The sleeper stack is especially dangerous, as a red-hot rivet or coal falling down may smoulder in a corner, and the stack break out into flame an hour or more after the men have knocked off work, when there is nobody on the spot to deal with the fire. I have known spans in three different bridges lost by fire in this way.

Fig. 11 is a useful suggestion for erection where staging is necessary, and where intermediate supports cannot be got in. It is a device which has been used several times in India, but it requires considerable time and care in erection; and long timber is preferable, though not absolutely necessary, as shorter timber can be spliced. The rakers should be supported at the strutted points by chains or wire ropes well set up by screw couplings. I have not drawn a cross section of the staging, as it does not appear to be necessary if you only note that cross bracing must be liberally used between the rakers and in the floor, as under a heavy load such a staging is very apt to go out of line. Side guys may sometimes be used, taking care not to get too much downward pull upon the staging. The centre truss is shown in the figure as a king post truss, but a queen post can, of course, be used, and with a long span I have used a treble queen post.

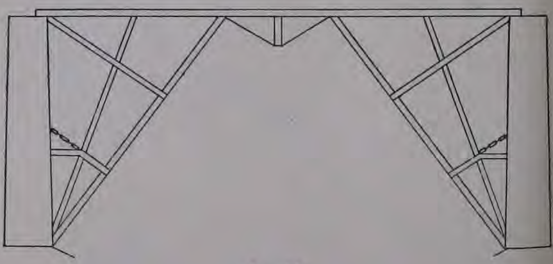


Fig. 11.

Once the staging is erected I do not know that there is so much advantage in a pin-connected over a riveted truss as might be supposed, as the riveted joints can be easily and rapidly secured by cotter bolts in the way indicated above, without waiting to drive the rivets. In some respects the riveted girders are easier of erection, as the solid trough of the bottom chord forms an excellent base from which to work, as the posts can all be stuck up at once.

The American type of design, however, with about half the number of members usual in European bridges, offers distinct advantages as regards rapidity. Still, I have put up a 275-foot span of the English type in four working days, with a good force of men, two good single travellers, and everything arranged. I do not mean finished ready for use, but so far finished as to be self-supporting. After the ordinary operation of erecting a girder on a staging, we come to the case of erection without staging, which leads us right to the Atbara Bridge. There are obviously two ways of dealing with this case, building by overhang and rolling over ; and I need scarcely remark that eye bar chords are here ruled out, except in the case of a cantilever, where they are sometimes used in the top chord. We are dealing just now with the case of moderate spans, not the very large ones, to which only would a cantilever be applied. The choice then between rolling out and building out would be greatly influenced by the prepossessions of the engineer. Rolling out would certainly be chosen by a Continental engineer, who is accustomed to look upon continuous girders as a desirable type, and who does not use the large panels in favour in America. The American engineer, on the other hand, will have nothing to say to a continuous girder, and consequently selects building by overhang, as in the case of the Atbara.

The obvious advantage of the rolling out process is the ease and safety of building on land, against which, in building out, if you drop a piece into the river your work will be delayed unless you have a spare span from which to borrow the missing part. In building out you also have the trouble of building a span to start from, which you must pull down again and send ahead.

On the other hand, the special disadvantage of rolling out is the severe strain to which parts of the girder are subjected, whereas in building out the strains are perfectly definite. In one sense the strains encountered in rolling out can be calculated, but any misfit in the temporary strutting, which would be required in all but a plate or very closely latticed girder, would produce very serious strains. The dangerous point is in the bay immediately above the rollers, in which, as you see in *Fig.* 12, the bottom chord has not

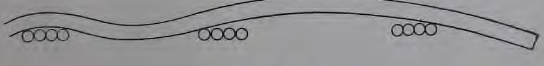


Fig. 12.

only to sustain the thrust from the overhang, but to carry as a beam the weight of nearly two spans applied at the roller points.

This is a matter which is too often neglected, to the permanent damage of the structure. It is no use to put down a certain number of rollers on a rigid bed, and assume that the load is divided between them, for it certainly is not, as the figure will show. The girder is elastic, and assumes some such shape as that shown in the figure, from which it appears that the outer rollers will have to carry the whole of the load. I should explain that though the amount of curvature is exaggerated in the figure, the nature of it is not, as you will see if you calculate out a case for yourselves; and however small may be the amount by which the girder leaves the hinder rollers, it will be sufficient to entirely vitiate the assumption that the load is distributed. This trouble can easily be surmounted by the device shewn in *Fig.* 13, where the rollers are arranged in pairs in balance beams,

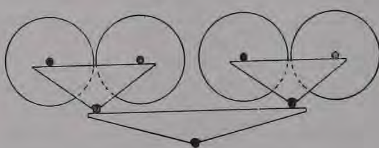


Fig. 13.

each of which again is carried by another beam, so that all the rollers must do an equal share of the work. The Embabeh Bridge, of which I spoke above, is a case in point. It is a continuous lattice girder of 8 spans of 243 feet, the bays between the lattices being about 6 feet. It was erected by rolling out, and numerous incipient cracks were found, principally in the lower chord. The metal, as stated above, was bad; but still the cracks show the overstrain to which it had been subjected by rolling out over rigid rollers. The rolling out apparatus would require to be supplied with the girders, as it would be difficult to make up in the field, but so would probably a traveller for building out, though it could be managed with spars and tackle. There are several cases on record in the French technical journals of girders which have failed while being rolled out.

The Atbara Bridge was a very good and practical example of building by overhang, and I cannot do better than describe it

Fig. 14 gives an elevation of one span and part of another being built out. The girder itself does not call for any special remark. The span is about 150 feet, divided into seven square panels, the depth being $\frac{1}{7}$ of the span. The members are built of pairs of channels laced together, except the main ties, which are eye bars of the usual American type, and the counters, which are rods. The traveller was all built of steel except a couple of beams on top, and weighed 9,000 lbs.; the reach was sufficient to plumb from the last post of a span to the first of the next span. Each span is a simple supported girder, and the members connecting them to enable the building out to be done are shewn in dotted lines. The horizontal tie between the spans is composed of steel channels like the top chord of the girders, made

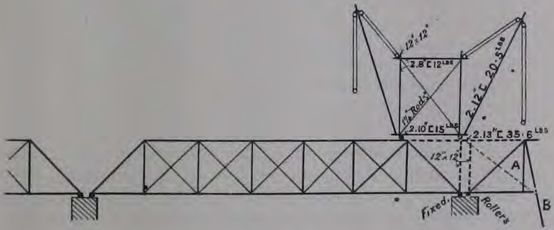


Fig. 14.

short enough to keep the nose of the girder, when cantilevered out, well above its seat on the further pier. The two posts are made of whole timbers, and only serve to keep the tie in position and carry the weight of the traveller. The shoes of the projecting span and its neighbour are separated by blocking and folding wedges, to enable the end to be lowered. When the completed span arrived over its pier, the end pin of each girder was suspended by a loop from a channel beam resting on two jacks, which first took up enough of the weight to permit the ties and wedges between the spans to be slacked back, and then lowered the end into its final place. The total weight of a span without floor being 56 tons, each jack only had to carry 7 tons.

The first step towards building out was to erect a span behind the abutment, to serve as anchor for the projecting span. This was done by an ordinary traveller, such as is shown in *Figs.* 8 and 9. Then the special traveller was got up into the position shown in *Fig.* 14, and building out commenced and went steadily on by a repetition of the same operations until the further shore was reached. A in the figure indicates a temporary tie, and B the first main brace, hanging down until the next bottom chord length is erected. The diary of the erection is as follows: — About seven days were spent in erecting the land or anchor span, and three or four in getting up the traveller and preparing to start, which was done on July 1st. The first span was completed 8th July, and till the 11th was spent in taking down the land span no longer required. The second span reached its pier 20th July, the third July 26th, the fourth July 31st, the fifth August 6th, the sixth August 12th, and the seventh and last August 16th, thus making in round numbers six weeks to erect 7 spans of 150 feet of an ordinary permanent railway bridge of full strength. Could the work have been attacked from both banks it would, of course, have been done in half the time. You will observe that with this method and with rolling out you are absolutely independent of the state of the river if only the piers are above water, as the end of the span can be used as a crane from which to build up the pier. We have a viaduct now being built in Burmah, which being 320 feet high, must almost necessarily be built by overhang. That work went in open competition to an American firm, who have adopted the practice usual in trestle viaducts of building it with an overhanging traveller, which can reach from one pier to the next, and having built the pier, travels the girders out. In this case the device has been pushed to the utmost possible limit, the forward reach of the traveller being 160 feet, the spans of the viaduct being 120 feet, and the tower spans 40. It is an open question whether for such an extreme height it would not have been better to have made the spans 150 feet, to have built them out like the Atbara, and then used the overhanging girder as the crane with which to erect the pier. But to revert to the Atbara. At the time of the incident so much nonsense was written about the Pencoyd Company, who built the bridge, having had previous information of what was required, and taking girders out of stock, that it will be as well to give you a true history of what really did happen, in order that you may have an idea of the rapidity with which it is possible under good organization to build a bridge of some size. The history of the transaction, with dates, is this :—

January 7th.—First enquiry for time and price for seven spans of 150 feet.

Answered same day, giving six or seven weeks time for delivery at ship, and sent standard plans.

January 13th.—Cable received that falsework could not be used.

January 16th.—Cable received giving train load.

January 24th.—Order and specifications received.

January 26th.—Length of spans changed, and other material information received.

January 27th.—Stress sheet sent for approval.

January 31st.—Shop drawings begun.

February 2nd to 11th.—Material ordered.

February 6th.—Work begun in templet shop.

February 13th to 20th.—Works closed on account of blizzard.

March 7th.—Total structure shipped from works.

April 26th.—At 3 p.m. received orders to replace a chord section 26 feet long, dropped overboard in London.

April 27th.—Shipped the piece at 9 a.m. (18 hours).

The circumstances of the case preclude the possibility of the girders or any part of them being taken out of stock, as has been asserted, or being standard, further than the expression means a general type. No girders have been erected precisely in this way before, so the whole of the work was designed and executed specially for the occasion. The Pencoyd Company own one of the largest steel works as well as bridge shops in America, so that there was no delay for material; what was not in stock was put through the mill at once, and there was no delay for assembling the girders, as soon as the pieces were riveted up the shop had done with them. The replacement of the lost chord section in 18 hours was in particular a fine bit of work.

I think, gentlemen, I can appropriately conclude my remarks upon American bridge types with this very spirited example of American work, but I should like to add that I do not believe the old country is played out, though the Americans have been sending us bridges, rails, and locomotives. One very considerable factor, which I think has not been generally appreciated, is that the present boom in trade started in England before it did in America, and work went to America simply because the English shops could not undertake to do it in any reasonable time, to say nothing of the price. When a shop is full of work for a year ahead it cannot be said to lose anything because a contract goes past it.

Since the Atbara a creditable piece of work has been done by an English firm, viz., the new girders for the Tugela Railway Bridge of 100 feet span, the first span of which, weighing 105 tons, was finished in nineteen days from the date of the order.

PAPER VII.

BARRAGES AND COLLATERAL WORKS ON THE NILE.

By W. Willcocks, Esq., C.M.G., Managing Director, Daira Sanieh Co.

A barrage is either a dam or a weir across a river. In N.E. Africa it is necessarily across the Nile. A dam impounds water in a reservoir, while a weir diverts it into canals. The two works have nothing to do with one another, and very often need to be constructed hundreds of miles away from one another. The Assuân reservoir dam, where the water will be impounded, is over 500 kilomètres away from the Assiout weir, where it will be utilized. It is on this account imperative that in all countries like Egypt, which depend for their agricultural development on irrigation, the Government or central authority should be sole possessor of all rivers, and have it in its power to construct its works wherever it pleases. Private individuals and companies may now and again have the good fortune to possess property where dams and weirs may be constructed side by side, but this will ordinarily not be the case; and if the rainfall and the rivers are ever to be utilized as they are in India and Egypt the Government must take up the question and carry out large and comprehensive projects with a strong hand and a full purse.

The land of Egypt owes its prosperity to the thorough comprehension of this fact by all its ablest rulers. Four thousand years ago the great kings of the 12th dynasty were engaged in the solution of questions of water storage and flood control, and constructed works which were the wonders of the world for many generations. To-day H.H. the Khedive, with the enlightened aid of Lord Cromer, is carrying out works such as Amenemhat and Usertesen never contemplated. We live in an age of great ideas and great achievements. The narrow horizons of our predecessors have been quite obliterated, and where in the past they confined their views to their own country, to-day we are all Imperialists, not only in politics, but in our every-day thought and work. Small things and small ideas are being crowded out. Egypt a few years ago began at Assuân. To-day it begins at the great lakes far away near the equator. The Nile, which for thousands of years concealed the secret places where it engendered its floods and its perennial waters, is to-day an open book. Yes, an open book which we Engineers in Egypt are daily and hourly studying, and which we are determined to so understand and utilize that we shall renew again the youth of even that most ancient country.

In 1883, when the British occupation began and Sir Colin Scott-Moncrieff first came out to Egypt, the country possessed one broken down and discredited old barrage at the head of the delta near Cairo. Timid Government after timid Government (all International Governments are timid, very timid) had had reports upon reports upon this Cairo barrage, but no one had had the courage to do anything. With the British occupation began the dawn of a new day. Sir Colin Scott-Moncrieff did me the honour to put me in charge of the work, and after we had examined it for a month we came to the conclusion that the weir was sound enough to do its duty. The want of soundness lay in the weak hearts and weak knees of the men who had been afraid to touch it. We determined to test it, but before doing anything we cleared the decks for action by throwing into the river all the sham fortifications and sham sentry boxes which had come in our way, and which had encouraged outsiders to look on this great work as a plaything instead of a barrage. Nothing sham should ever be introduced into any work which interferes with the flow of rivers.

The accompanying plate (*Plate* I.) gives you eight different sections of weirs. The boldest design is that on the Kistna, worked out by that prince of irrigation engineers, Sir Arthur Cotton, who with Sir Proby Cautley shares the high honour of having been the greatest irrigation engineer of the 19th century. In one short lecture I can give you no details, but I ought to give you the principles on which such works are designed. All such works are built on the sandy beds of rivers, and hold up 4 mètres head of water as a maximum. The works stand entirely by friction. The water held up pushes horizontally with an easily calculated force, and the submerged weight (practically half the weight) of the work should not be less than 30 times the pressure of the water if the sand is coarse, and 50 times the pressure if the sand is fine. For my part I prefer weirs made of dry stone well packed to weirs made of masonry. They are elastic, handy, and cheap. Many engineers, however, prefer a masonry floor. If you have a masonry floor, its submerged weight must be such that it can stand the upward vertical pressure of the head of water. In other words, the thickness of the floor must be nearly equal to the extreme head of water. Look at the three lowest sections on the plate. The third from the bottom is one of the temporary barrages on the Damietta branch constructed in 1885–86–87. It was of loose stone, and worked admirably. The second from the bottom is the Cairo barrage as it was in 1885. We kept on adding pitching until we made half the weight of the work fifty times the pressure. The bottom section of all shows the work as repaired by Colonel Western and Mr. Reid in 1887–91 at a cost of £500,000. You see the 25 mètres of upstream apron which they added, the good solid masonry they put on the top of the old floor, and the substantial pitching downstream. They also thoroughly renewed the regulating apparatus and the lock gates.

Plate II. gives you a plan and sections of the Cairo barrage in 1884. You will notice that the original deep channel of the river was closed by a loose stone barrier 10 mètres in depth at the deepest part. This stone was tipped out of boats, and has had no cementing material except Nile mud. This is the boldest section in any work in existence to-day. Since the repairs of 1891 the upstream apron was further strengthened by Mr. Foster by an additional apron of clay 2 mètres thick and 20 mètres wide, laid upstream of the masonry apron after the sand had been dredged away. In 1897 the Cairo barrage was further strengthened by Major Brown. Vertical holes about 3 mètres apart were bored in the piers. Each hole went down from the top of the pier or the roadway to the sand underlying the foundation. These holes were filled with liquid cement from the top. The cement found its way into all the crevices and hollows in the foundations and solidified them. The cost was only £6,000.

The Cairo barrage being capable of holding up only 4 mètres of water, while Sir William Garstin was desirous that it should hold up $5\frac{1}{2}$ mètres at the beginning of the flood, it became necessary to build a subsidiary work below the existing one. Major Brown has designed and constructed a work 1 kilomètre downstream of the original barrage. Mr. Octavius Brooke is the resident engineer. The old barrage will now hold up 3 mètres, and the new one $2\frac{1}{2}$. It consists of a solid core of cement masonry 7 mètres deep and 3 mètres wide. On either side is a mass of clay 10 mètres wide and 2 mètres thick, overlaid by rubble stone 2·50 mètres thick and 15 mètres wide upstream and 45 mètres wide downstream of the core. In my opinion the cement masonry and clay are quite unnecessary in a muddy river like the Nile. The new work will cost £500,000.

Plate III. gives you a block plan of the Cairo barrage. I want to draw your attention to three things here.

(1). The thick dotted lines represent the alignment of the river upstream of the barrage which the engineers are striving to attain. This is being done with the intention of making the water come straight on to the barrage, and not from a side. The object is sound. While this process is going on, however, great blocks of sandy soil are being cut away every year by the river in flood, and the sandy material finds its way into the central canal and causes heavy silt deposits, which have to be annually dredged. In fixing sites of weirs and heads of permanent or temporary canals great pains should always be taken to choose points where there are no shoals or shifting islands liable to scour in flood just upstream of the work. A clear reach of the river, at the tail of a curve in hard soil by preference, should be chosen, and the channel upstream of the work maintained by spurs and pitching if necessary. I calculate that 30 per cent. of the silt clearances of canals could be economized if this principle were not lost sight of.

(2). The second point I want to call your attention to is the faulty position of the central canal head. All canal heads should be placed as near as possible to the weir from whose upstream side they take. You have the river under control, but you cannot control muddy flood water when it is hundreds of mètres away from the edge of the main stream. The proper position for the head would have been just upstream of the right flank of the Rosetta branch barrage, and I hope some day to see the necessary modification made. The masonry regulators at the heads of the canals should be placed as near as possible to the take-off of the canals The new Tewfiki Canal head at the extreme right is excellently placed in this respect, while the old Behera head regulator on the extreme left is much too far back. When the regulator is far back, the operation of regulating the water supply in flood causes heavy silt deposits upstream of the regulator, and these have to be removed annually at great expense.

(3). The third point I draw your attention to is the widths of the canals. The scale of the plan is too small to allow of your seeing this properly on the plate. When you design a weir you have necessarily to design the head works of the canals taking off from above the weir. Hitherto it has generally been considered that the deeper the canal the less chance was there of silt deposit in flood. As a matter of fact, the opposite is the case. Examine the cross section of any river in flood. In the deepest part there may be a depth of 20 mètres, and of 1 mètre in the shallowest part, and the river will be flowing on majestically, and not silting. You will also find that the maximum velocity, which may be 3 mètres per second, will be exactly over the deepest part, and the minimum velocity of, say, 30 centimètres per second, will be over the shallowest part. In order to keep moving on, each depth of water will need its own particular velocity, or each velocity will need its own depth. Different rivers will have different relations. Take a series of very careful depth and velocity observations in flood, and find out the existing relationships. Then when you are designing your canal, if you find that you can most conveniently give a depth of 5 mètres of water in flood, say, find out the velocity suited to the depth and design accordingly. If this were properly attended to, another 30 per cent. of the silt clearances of canals would be avoided. These points may seem insignificant, but it is often the neglect of these very considerations which makes otherwise good and sound projects pay very poor dividends.

I have now finished with the Cairo barrage.

Egypt proper consists of 6,000,000 acres of cultivable land. Of this area 4,000,000 acres are rented at £5 per acre per annum and 2,000,000 acres at £1 per annum. Practically one-third of the country is undeveloped, and this because the summer supply of the Nile, on which the modern perennial irrigation of sugar-cane and cotton depends, is not sufficient. To thoroughly develop the country we require a reservoir capable of supplying annually to

Egypt 6,000 millions of cubic mètres of water, or 600 cubic mètres per second additional through the summer. The Government has made a beginning by commencing the execution of two works. The first is the Assuân dam, which will store 1,000 millions of cubic mètres of water, and the second is the Assiout weir, which will allow of the water being utilized. They are estimated to cost £2,000,000 between them, of which three-quarters go to the dam and a quarter to the weir.

The Assuân dam, which I had the honour of originating and designing, is a type of work which, if successful, will mark an epoch in dam building. The dam is insubmergible in flood, and provided with numerous undersluices capable of discharging the flood waters of the Nile. The muddy flood waters will be able to pass without parting with their silt, while the surplus of the comparatively clear winter supply will be stored for use in summer. *Plate* IV. gives you a gauge diagram of the Nile at Assuân, showing you the comparative heights of the river in flood, winter and summer. If the flood waters were obstructed, the reservoir would be choked up with mud and silt and obliterated in a few years, while Egypt without its muddy water would be poor indeed. With the proposed design of dam it is hoped that all difficulties on this head will be avoided.

Plate V. gives you a longitudinal section of the dam, which is 2,000 mètres long on one straight line. I originally designed the dam along a more or less crooked line, following the soundest rock, but the International commission appointed by the Egyptian Government changed it into a straight line for the sake of adding dignity to the work. This commission had Sir Benjamin Baker for one of its members, and improved my original design in many respects, but I think they would have done well to have left my crooked alignment alone. The dam is pierced by 140 under sluices of 7 mètres by 2 mètres and 40 upper sluices of 3·50 mètres by 2 mètres. The total area of opening will be 2,240 square mètres. The greatest height of the dam will be 35 mètres, and the head of water will be 20 mètres. All but 20 sluices will be lined with granite ashlar. Twenty will be lined with cast iron. I objected to the cast iron because I think that iron and stone contract and expand in different ways; but the International commission approved of the iron. An extraordinary flood of 14,000 cubic centimètres per second will be discharged at a velocity of 6 mètres per second, and an ordinary flood at 4½ mètres per second. The regulating gates will be Stoney's patent self-balanced roller gates, such as are in use on the Manchester Ship Canal.

Plate VI. gives a plan and section of the dam at one of the under sluices. As far as the navigation channel is concerned, the drop of 20 mètres will be got over by 4 locks. The upper lock gates will be 20 mètres high, as the navigation has to go on in winter when the reservoir is full, and also at the end of the summer when it is empty. The gates will be single leaved, rolling back into recesses at right angles to the direction of the lock. I cannot leave this subject without recording the loss the works have suffered by the death of Mr. Stoney, who designed the gates, and Mr. Wilson, who succeeded me as Director-General of Reservoirs. The resident engineer on the work is Mr. Maurice Fitzmaurice.

It is anticipated that the works will be completed in 1902.

The Assiout weir is being built across the Nile at Assiout, 500 kilomètres downstream of the Assuân dam, and below the head of the Ibrahimia Canal. *Plate* VII. gives you a cross section of the work as designed by me. There will be 120 openings of 5 mètres width and 9 mètres height. The piers will be 2 mètres wide. I had proposed for the floor, as you can see, up and downstream curtain wells of 4 and 5 mètres depth respectively, with 4-mètre deep wells under the piers and a 2-mètre deep floor. I think that for works built on sand saturated with water wells should be provided under all abutments, piers, and lock walls, in order to make the depths of foundation bear some proportion to the weight to be brought on it. Mr. Wilson, however, who succeeded me, thought otherwise, and supported by Sir Benjamin Baker substituted one broad floor 3 mètres deep everywhere, with 5-mètre deep iron sheet piling as up and downstream curtains. *Plate* VIII. gives you the design of the iron sheet piling. This section is very like that of the original Cairo barrage. Mr. Stephens is the resident engineer in charge of the works, which will be completed in 1902.

As the International commission which controls the finances of Egypt refused to sanction the funds for building either of these works, in spite of the eager demands of all the Egyptian landowners, their construction would have been indefinitely postponed had not Sir Ernest Cassel come forward with the funds, and, with Mr. John Aird as contractor and Sir Benjamin Baker as consulting engineer, undertaken their completion in 5 years. There is every prospect of the works being completed before the specified time.

While preparing plans and estimates of the Assuân dam I also prepared the plans and estimates of an alternative project for a reservoir in the Wady Rayan depression. This depression exists in the deserts about 100 kilomètres to the south-west of Cairo, and touches the oasis of the Fayoum. Mr. Cope Whitehouse, an American gentleman, suggested it as a suitable site for a reservoir. *Plates* IX. and X. give you a plan and section of the proposed reservoir canal. The length would be 25 kilomètres in the Nile Valley and 35 kilomètres in the desert. The works were estimated to cost £3,000,000, and provide 1,300 millions of cubic mètres of water in summer. The problems connected with this canal are especially interesting, but as the works have not been carried out, I am not justified in doing more than alluding to them. To anyone interested in such works I can recommend a study of this reservoir, which Colonel Western and I worked at for 2 years, and which are given in my book on Egyptian irrigation. In happier days Egypt may carry out this work. It would constitute an inland sea covering over 300 square miles in the heart of the desert, and be the health and pleasure resort of Europe in winter.

You will remember that I stated some time ago that Egypt needed for its thorough development a reserve of 6,000 millions of cubic mètres of water, of which the Assuân reservoir would supply the first instalment of 1,000 millions. Where is the remainder of the supply to come from? It will come from those vast lakes which constitute the sources of the Nile, and where alone we deal with quantities of water which approach these figures. It is no ordinary justice which has entrusted to England the control of these lakes. By whose energies and perseverance were they discovered? Was it not by Speke, by Grant, by Burton, by Baker, and by Stanley, who are all of them Englishmen? What a poor compensation would it be to them to know that the Nile sources could now be depicted on plans, and that nothing more could be done with them. It would indeed be a real triumph and a real compensation if the resources of modern science could be employed to utilize these great lakes, and by the construction of suitable works to insure that the whole valley of the Nile, from the Abyssinian Mountains to the Mediterranean Sea, should be well watered through summer drought as through flood inundation. It is to me a source of no small gratification that for 10 years and more I have not ceased to plead the importance of these works, whose execution has been placed within the range of practical politics by the conquest of the Sudan and the near completion of the Uganda Railway.

Plate XI. gives you a plan of the Nile from the equator to the sea. The length of the Nile is over 6,500 kilomètres. Lakes Victoria and Albert Nyanza at the sources of the White Nile could be converted at a cost of £1,000,000 into reservoirs capable of supplying annually 18,000 millions of cubic mètres of water, of which 12,000 millions could reach Egypt as against 5,000 millions required. These works will certainly be undertaken on the completion of the Uganda Railway. What a rich harvest Egypt will reap from that work! From the equatorial lakes to the frontiers of Egypt proper the course for this water will be clear and unimpeded except on one length of 300 kilomètres in the well-known "Sudd" regions of evil repute. Here we have the bars of living vegetation which block the course of the Nile. You will understand the position better on the longitudinal section (*Plate* XII.), where you see that the slope of the river is insignificant and the barring of the waterway is not difficult.

The waters flow down many spills and channels, though at present there are two main branches, the Gebel and the Ziraf, of which the former is much the more important. In this reach the slope of country is insignificant, but if left to itself the river would maintain channels of considerable magnitude, just as the Sobat does, were it not for the bars of floating vegetation which block its course. These bars are sometimes as much as five mètres in thickness and capable of turning nearly the whole supply of the river out of its course. They are formed of papyrus weeds and water-grasses, which grow in the peaty banks of the lagoons and marshes traversed by the river, and which, under the double action of a rising flood and strong winds, are torn up and driven into the channels wherever they are confined in width, and there jammed into solid masses of floating weeds many mètres in thickness, and capable of supporting the greatest weights. The higher the floods the greater are the masses of weeds torn up from the peaty banks, and the more serious the "sudds." All these plants, with their roots without tenacity, are the product of clear water, and can only exist in clear water. If by any means muddy water could be substituted for the clear waters, and willows and osiers substituted for the papyrus, a beginning might be made of the permanent removal of these bars or "sudds."

To clear away these "sudds" and insure good working channels for the waters of the Nile three classes of works will be needed. One will be the widening and straightening of the main channel by dredging, beginning at the extreme downstream or north end of the "sudd" region and working upwards. The second will be the staking and fixing, by means of substantial iron piles driven deep into the ground, of the 4 or 5 kilomètres of channel where the floating weeds are excessively mobile and unmanageable. The third will be the training of the river from the extreme upstream or south end of the region, and working downwards. This latter will be an extremely interesting work. I imagine it will be done in this way. A width of some 500 mètres will be taken for the bed of the river, and in continuation of the existing banks impediments of stakes and brushwood will be run out for a length of some 15 or 20 kilomètres, and all side channels will be well barred. When the muddy flood waters of the Assua and other right-hand tributaries come down in flood between May and September, the mud and silt will be caught by the stakes and brushwood, and incipient banks will be begun. On these banks will be planted osiers and willows and other plants with tenacious roots capable of flourishing in water-logged soil. This work will be continued year after year until it meets the dredgers working upstream. When the whole work has been completed one of the biggest engineering problems of the day will have been solved. Fortunately, however, it will not be necessary to wait for the results till the works have been completed. These works in their degree will help from the first moment of inception. We have had a splendid object lesson this year of what we may expect from these upper waters of the Nile. The Nile flood practically failed in 1899. A drought was anticipated in Egypt during the summer of 1900, that is, the summer just passed. Fortunately for Egypt, the Khalifa was annihilated in November, 1899. Within a month of the final victory Sir Reginald Wingate, at the request of Sir William Garstin, which I may say was made in part owing to my representations, had started an expedition of 1,200 Dervish prisoners under Major Peake and two naval officers, with four gunboats, to cut a way through the "sudds" and open up the channel of the Nile as far as possible. Major Peake's work cost £15,000, and freed a quantity of water which saved Egypt from drought, and made a present to the country of £4,000,000. It does not fall to the lot of many to make such expeditions. *Non teligit quemcunque adire Corinthum.*

Speaking as I am to an audience of Royal Engineer officers, I cannot close my lecture without expressing the hope that just as in the past famous men of your Corps have with masterful hands laid deep the foundation of agricultural prosperity in India and Egypt by being the pioneers of the modern irrigation works in those countries, so in the not distant future your Corps will again be the first to enter the field and apply the lessons which we have learnt in India and Egypt to our new possessions on the Orange and the Vaal. There we possess countries whose development will be impossible without liberal and comprehensive schemes of water storage and utilization, under conditions of muddy flood rivers, poor summer supplies, and long periods of drought, such as my lecture has made you cognizant of in Egypt. There also, as in India and Egypt, it would well become the men of your Corps on the very day that they sheath their swords to turn their attention to those great and beneficent works of land improvement, which would do more to reconcile our new fellow-subjects to their changed conditions of life than oceans of good words and good intentions. As your Corps have had the great privilege of being the first engineers to enter the field, they should now, as in the past, look on these works as their birthright. Having been in the forefront to conquer these lands and make them a part of the British Empire, it should also be their boast that they led the way in the conversion of much of this desert land into cultivated fields well watered everywhere, like the garden of the Lord, like the land of Egypt.

PAPER VIII.

UGANDA RAILWAY.

By F. L. O'Callaghan, Esq., C.S.I., C.I.E., M.I.C.E.

When the proposal for the construction of a railway from Mombasa, on the Coast of East Africa, to the shores of Victoria Nyanza was first mooted, the Imperial British East African Company consulted three railway experts, namely, the late Sir John Fowler, General Sir E. Williams, R.E., and Sir Guilford Molesworth.

Each of these experts made a report, those of the first two being based more or less on abstract reasoning. That of Sir Guilford Molesworth, on the other hand, was derived from a careful study not only of such maps as had been prepared from time to time and were available, but of all accounts of the country that had been written by various travellers, none of whom, however, had viewed the country with the eyes of an engineer looking to its possibilities for railway communication, and whose barometric levels, for example, showed only the more salient features.

The reports of Sir J. Fowler and General Williams gave estimates of cost for a light railway laid almost as a surface line, but for the most part unbridged and unballasted. Sir G. Molesworth's report indicated generally the route which he considered would prove to be the best, and contained a diagram showing the approximate levels along that route. His surmises have proved to be marvellously close, both as regards the best alignment and the profile of the country along the line of the railway as now laid out, showing how a trained engineer of great experience may, by careful study, be able to draw correct inferences from very meagre data. This report gave figures as to the probable cost of the first half of the railway, on the assumption that the details of the country nearly approached those of a locality known to him with which it had been compared; but as regards the latter portion he wrote, "there is every reason to believe that a line of railway must be difficult of construction and very costly." The report contained a suggestion for a "barometric reconnaissance survey" on the route indicated.

In the latter part of 1891 a party of Royal Engineers, consisting of Capt. Pringle, Lieuts. Austin and Twining, and Sergt. Thomas, under the command of Capt. (now Lieut.-Colonel) Macdonald, R.E., was deputed to make a reconnaissance survey of the kind suggested. The field work occupied the party for nearly 11 months, during which time its members, while on their way to the lake, surveyed routes aggregating over 2,000 miles in length, and on the return journey to the coast examined nearly 700 miles of alternatives. The preparation of reports and plans occupied about four months, and these were submitted to Her Majesty's Government in March, 1893, and subsequently were presented to Parliament in the form of a Blue Book.

The large-scale map prepared by the survey party has proved a most valuable asset. Part of this map (with some additions since made) is before you (*Plates* I. and II.), and on it is shown by a strong continuous line the course of the railway now under construction, while the different routes examined by Capt. Macdonald's party are marked in black. The shore line of the lake has been corrected according to recent surveys, and details of the Nandi country, as well as of Usoga and Uganda, have been filled in from later information.

The manner in which Capt. Macdonald's reconnaissance survey was carried out is described in detail by Capt. Pringle in the above-mentioned report, and is worth studying, as showing how a survey of this kind may be conducted, and how considerable accuracy may be achieved by careful work, although done hurriedly, by approximate methods, and under considerable difficulties.

The map has, in regard to the main features of the country, successfully stood the tests it has been subjected to, both by the triangulation between Kibwezi and Lake Victoria, made by Capt. Smith, R.E., during 1895–97, while road making under the late

Capt. Sclater, R.E.; and by the theodolite and chain traverse made for the permanent staking out of the railway.

By the end of the coming year it is hoped that the completion of the railway telegraph to Port Florence, the terminus on the lake, will enable the relative longitudes of that place and Mombasa to be finally determined, as well as those of such intermediate stations as may be desired.

The general configuration of the country shows a steady rise from the coast inland for about 350 miles to the highlands of Kikuyu, then a sudden dip into a valley, varying from 15 to 20 miles in width, and running generally in a north and south direction, an equally sudden rise to a second ridge, the Mau, and a gradual lescent to the lake.

The valley, called the Great Rift Valley, is one of the remarkable features in this part of Africa, and extends for several hundred miles. Apparently it is due to an immense subsidence or "down-throw." It has several extinct volcanoes along its floor, and many lakes, most of which are salt. The crest of the eastern escarpment varies from 7,000 to 11,000 feet in height above sea level, and that of the western one is somewhat higher.

The descent into and ascent out of this valley were the two difficult problems in the construction of the railway, so far as the physical features of the country are concerned.

In August, 1895, Her Majesty's Government having decided to construct the railway, a small grant for preliminary expenses was obtained from Parliament, a supervising Committee, with Sir Alexander Rendel as Consulting Engineer, was appointed in London, while a Chief Engineer, with a proportion of staff sufficient for the work to be at first undertaken, was despatched to Mombasa, where the party arrived towards the close of December in the same year.

The matters requiring the Chief Engineer's immediate attention were the preparation of a base on the coast and the survey of the best route to the summit of the coast hills, these hills rising rapidly for the first 15 or 20 miles inland from the sea.

It was at once obvious that the best site for a base was to be found on the island of Mombasa, because excellent harbours existed on both sides of this island, and on it was the only large piece of open and tolerably level ground available, as had already been noted in Capt. Macdonald's report.

The preparation of the base included the following :—

1. Housing of staff and shelter for imported labour.

2. Preparation of a station site, and sites for store yard, stacking ground for permanent way materials, girders, and such like.

3. Construction of a landing stage for stores, and its connection by rail with the stores yard, and stacking grounds.

4. Construction of workshops for the erection and repairs of locomotive engines and rolling stock, and for other work connected with the railway.

5. Organization of offices for accounts and stores.

6. Connection of the island with the mainland by a temporary bridge.

7. Water supply, including erection of condensing plant.

8. Organization of an agency in India for the supply of labourers and of food for them, besides sundry stores procurable in that country.

The survey parties arranged were eventually three in number. The first, a strong party, examined the country in detail, staked out the railway, for construction, ahead of the working parties, and prepared the usual large scale plans (400 feet to 1 inch) and working sections.

The second party was despatched to Kibwezi (mile 190) to work backwards until met by number one party. This was desirable, as the country is somewhat intricate between the 150th and 190th miles, and it was important that the plans and sections should be ready in time to prevent any delay to construction works.

The third survey party was sent on to Kikuyu to investigate the different routes that might be possible from the Athi plains across the escarpment and into the great Rift Valley, and, when the best route was ascertained, to mark it out and complete the working plans and sections; then to go forward and similarly examine the Mau range on the west side of the valley, fix on the best point for crossing this, the last and highest of the two great ridges to be surmounted, settle on the best route to the lake, and finally to prepare working plans and sections.

The first and second parties joined up in November, 1897, and these continued the location work from mile 190 onwards to mile 325, where the third had started, completing this work by October, 1898; but the third party did not finish its task until April, 1900.

The difficulties which had to be overcome by these parties varied somewhat in different localities, but on the whole their work was of an arduous nature.

On the first 200 miles from the coast the country, for the most part, is covered by dense thorn bush, which has to be cleared for every survey line run.

This bush is infested with tsetse fly, fatal to all beasts of burthen, thus limiting the means of carriage to that by native porters; the "fly" district extends for some 30 miles or so beyond the thick bush, or up to the 220th mile.

The Kikuyu and Mau ranges are clothed by heavy forests with thick undergrowth, making survey work tedious and difficult.

Up to mile 320 the country is sparsely inhabited and produces no surplus food stuffs, while water is scarce and bad, being in most cases impregnated with salts injurious to health.

Moreover, in addition to these difficulties inherent to the country, the first party, during the early months of 1896, was impeded by disturbances due to a local rebellion, which made it dangerous to establish isolated camps without strong escorts, and escorts were not readily available, all troops being employed in suppressing the rising.

The positive hardships endured by the first survey party were severe; frequently, by the desertion of porters, they were in danger of starvation and of the horrors of thirst, while all, both Indians and Europeans, suffered severely from malaria fever, and the former from ulcers and sores due to the thorns of the aloes, cactus, and other bushes through which they had to cut their way.

The third survey party found that, as surmised by Sir Guilford Molesworth in 1891, the lowest point on the Mau range was between the Guaso Masai Valley on the east and Nyando Valley on the west, the summit being 8,321 feet over sea level, the ground falling away very quickly on both sides. The highest point is in the 489th mile, and for some little distance on either side works will be easy.

The ruling gradient adopted for the coast section was 2 per cent., with 10°* curves as a maximum, and the same ruling gradient has been used over the Kikuyu and Mau ranges, but in combination with 7°† curves.

Wherever the permanent working section showed heavy earthwork, which could not be completed in time to allow of the rails

* 573 feet radius.
† 816 feet radius.

being laid over them, temporary lines, commonly called "diversions," were marked out, with gradients as steep as 3 per cent. and curves of 14° in order to keep these diversions as near the natural surface of the ground as possible, and thus keep down both their cost and the time necessary to construct them.

On the first portion of the railway up to Nairobi (326th mile) the aggregate length of diversions was about 40 miles. On the second portion the total length of these temporary lines will not fall far short of 44 miles.

The selection of temporary lines, as a rule, preceded that of the final permanent location, and required quite as much care and study of the ground.

Notwithstanding the care taken, some of the temporary works were of considerable magnitude; the first, of course, was the temporary bridge connecting the island of Mombasa with the mainland; next, a trestle structure across a ravine in the 12th mile; while every river met had to be temporarily crossed by bridges made with sleeper stacks and girders. Many other temporary structures were required, such, for instance, as stages for water tanks at temporary stations, for which timber is used.

While the first party of Engineers was on its way to East Africa, permission was obtained from the Government of India to recruit labourers in that country, this permission being necessary under the Indian Emigration Laws; arrangements were also made with that Government for the loan of an experienced engineer from their Public Works Department, as well as of a medical officer, with sufficient hospital staff. These in the first instance were engaged in selecting labourers, and about one thousand Indian navvies, with a proportion of carpenters, blacksmiths, rivetters, masons, etc., were shipped for Mombasa; several surveyors and draughtsmen, and also European and Eurasian overseers, were procured and despatched. An accounts officer was borrowed from the same source, who selected and engaged a staff of Indian accountants and clerks, and arrived in Africa with them during February, 1896.

In England a supply of tools, plant, workshop machinery, tents, iron houses, permanent way materials, small bridge girders, timber beams and scantlings, locomotives and rolling stock were contracted for, and the first shipment reached Mombasa in April, 1896, followed by others at frequent intervals.

The temporary bridge to connect the island with the mainland—

over a channel about one-third of a mile wide, with a depth of water up to 17 feet at high water—was then put in hand and completed by the 4th August, 1896, on which date the rails were laid over it, and platelaying may be said to have commenced. This bridge had to carry the whole of the traffic passing up the railway for a period of nearly three years. Before two years had elapsed the supporting piles were nearly destroyed by that marine pest the *teredo navalis*, and heavy renewals were necessary. *Plate* III. shows the cross section of a pile taken out in 1898.

It is usual to guard timber used in marine works either by sheathing it with zinc or by covering all exposed surfaces up to high-water mark with "scupper nails," *i.e.*, a nail with a large flat head and a very short shank. These nails very quickly rust and cover the timber with a hard layer of red oxide of iron, thus preserving the timber from attack.

The conditions under which construction had to be carried on precluded heavy works of any kind being executed far from the rails, because the carriage of food and water in large quantities, except by rail, was practically impossible. The "telescopic" method, therefore, was imperative, and no pains were spared to obtain, even at the cost of very steep gradients and sharp curves, as nearly a surface line as possible. Once the rails were laid, the heavier permanent cuttings, embankments, bridge, and culverts could be attacked with large gangs of workpeople to the full extent that economy of construction rendered advisable, and completed without further difficulty.

In the first instance the utmost that could be done was to keep a gang of about 300 Indian earthwork coolies at from one to two miles in advance of railhead, clearing away the bush and preparing the temporary surface line.

The supplying of these coolies, as well as the platelaying gangs, with food and water was a constant source of anxiety. The accumulation of spare food sufficient for some few days was not a matter of very great difficulty, but water, which had to be carried daily by train, and of which the supply in Mombasa was limited, was a serious matter, and any breakdown in its supply might have been followed by terrible consequences. At the railway base it was necessary to erect heavy plant for the supply of fresh water by distilling sea water, because the wells in the island gave little more than sufficient for the requirements of the fixed population.

The diagram *Plate* IV. shows the advance of the rails month by month, the total number of labourers employed on the works, and the rate at which locomotives and rolling stock were supplied. On the 10th November the railhead was at mile 460 on the eastern slope of the Mau range. The number of labourers had attained its maximum during August last, and the full supplies of locomotives and rolling stock were completed in December, 1899, and in April, 1900, respectively.

The number of workpeople to be employed depended on the amount of work opened up by the advance of the rails, and thus their increase, as shown in the diagram, is proportionate up to a certain point to the advance of the line.

The principal permanent structure on the first 360 miles of the railway, *i.e.*, up to the Kikuyu Escarpment, is the long steel bridge on screw piles connecting the island of Mombasa with the mainland, completed on the 28th June, 1899, and now called the Salisbury Bridge (*Plate* V.). The spans are 60 feet in the clear each, and the roadway, with a footway for men engaged on the railway, is on the top of the girders.

The next largest bridge is one of four spans of 60 feet over the Tsavo River, mile 132 (*Plate* VI.).

Twenty-six other girder bridges of 40-foot span and upwards have been built, or are building, on this length, as well as a very large number of drains, culverts, and minor girder openings.

The bridges are of three types as regards piers and abutments—first, masonry piers and abutments; second, piers and abutments of concrete; and, lastly, trestle piers, composed of 3-foot diameter steel cylinders, braced together with cross girders and angle iron, the cylinders being filled with concrete.

Small drains are provided for by stoneware pipes, 12 inches and 18 inches diameter, laid on a concrete bed; larger drains are of oval steel cylinders on concrete, while arched culverts from 3-foot to 15-foot spans are usually of concrete. The whole of the masonry and concrete work is made with Portland cement, because no limestone, except coral, on the coast, is to be found; concrete and masonry, therefore, are very costly, and when possible they have been avoided.

The largest single-span girder bridge on the railway is 100 feet clear span, and there are two such spans (both with "through" roads). The girders are triangulated open web, weighing with cross girders, etc., 65·6 tons each span; all other girders are of the plate web type, with road on top of girders, and are classed as follows:—

60-foot	spans,	weighing	22·3 tons	each span.
40	,,	,,	10·15 ,,	,,
20	,,	,,	3·16 ,,	,,
12	,,	,,	1·16 ,,	,,
10	,,	,,	0·19 cwt.	,,
6	,,	,,	0·11 ,,	,,

On the 13 miles required for the descent from the Kikuyu summit to the floor of the Great Rift Valley eight ravines are met with, which are being crossed by steel trestle viaducts varying from 120 feet to 780 feet in length, and from 32 feet to 85 feet in height at the deepest points. Embankments over these would have necessitated very long and costly culverts owing to the steep side slope of the escarpment, and in many instances it is doubtful if the earthworks would have stood, while they would in any case have been a constant source of trouble and anxiety.

Plate VII., *Fig.* 1, gives in elevation, and *Fig.* 2 in section, a general idea of these viaducts. They are of the ordinary trestle type, the tower spans being 20 feet, the intermediate spans 40 feet, and the batter of the legs 1 in 6.

Fig. 1 shows also the method of erection. A traveller, with jib long enough to reach to the forward tower, stands on the last completed span, and the pieces being brought up on a lorry which passes underneath the traveller, as shown in cross section *Fig.* 3, are then laid hold of by a tackle and traversed forwards into place, or raised and lowered by winding on one winch and paying out on the other.

A third tackle at the mast takes the tail of the 40-foot girders, which are the heaviest pieces, when putting them into position. Besides these main tackles there are light ones worked by hand for raising and holding in position the smaller parts. By these means the viaducts can be erected very rapidly, and when one is finished the traveller is conveyed on its own wheels to the next.

The erection of these is now in progress. That the spans adopted are the most economical is proved by the fact that the total weight of the girder work is almost exactly equal to the total of the bents or piers.

Along the floor of the Rift Valley itself, which is crossed very obliquely, the works are of a simple character, only two streams of any magnitude being met with. The first 15 miles up the slope of the Mau range is also easy, but from mile 465 onwards to 539 is the most difficult and costly part of the whole of the railway. On these 74 miles there will be twenty-eight steel viaducts, similar to those on the descent from Kikuyu, varying in length from 160 feet to 880 feet, and in height from 30 feet to 110 feet, the severe side-slopes here also rendering embankments with consequent culverts inadvisable. In the 526th mile a narrow high spur necessitates a short tunnel about 200 yards long, the only one, strange to say, on the whole length of this railway. Between mile 539 and Port Florence (mile 582) eleven rivers have to be crossed by bridges varying in size from one span of 40 feet to three spans of 60 feet.

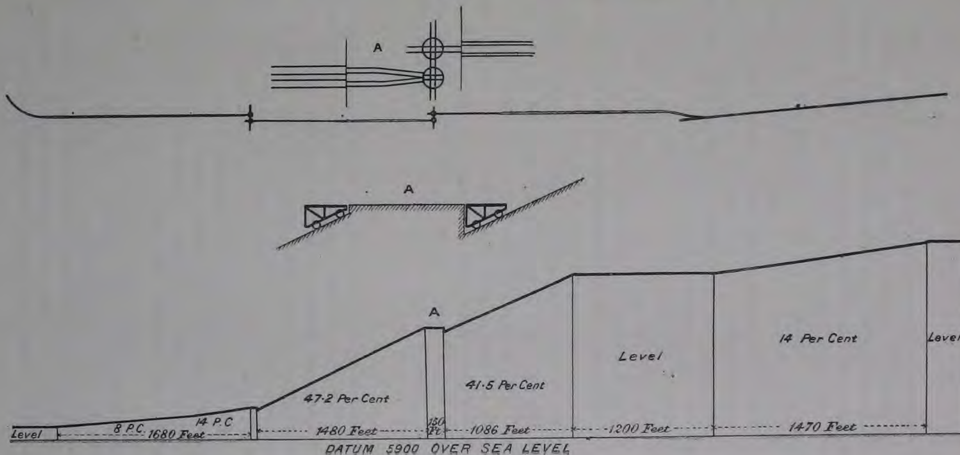
At Port Florence there will be a small engine-repairing shop, and a jetty at which steamers can load and discharge cargo.

Station buildings are of the simplest character, made of timber framework covered with galvanized corrugated iron, easily removable to other sites when advisable.

The headquarters station has been fixed at Nairobi (326th mile), 5,600 feet above sea level, the last point at which an open level plain is found before entering the broken country of the Kikuyu range. Here are being constructed the central workshops and offices, the elevation insuring a tolerably cool climate. Other engine-changing stations, besides the two termini, are at Voi (mile 100), Makindu (mile 207), and Nakuro (mile 450).

On the portion of the railway between Kikuyu and the Lake the first temporary structure is in the 363rd mile (*Plates* VIII. and IX). Here the heavy works on the descent into the valley commence, and as they would evidently take considerably over a year to complete, it was decided to construct a rope lift to lower materials into the valley. This lift or incline overcomes a difference of level of 1,523 feet, and consists of four portions. Two of them—one at the top and one at the bottom having inclinations of 16 per cent. and $9\frac{1}{2}$ per cent.—are laid as double lines, with drums at the top of each, round which a steel wire rope is passed. The railway wagons are run down and up these inclines, the full wagons going down, hauling the empty ones up, speed being regulated by brakes on the drums. The two middle portions are on inclines of nearly 50 per cent., similarly worked by steel wire ropes, $1\frac{1}{4}$ inches in diameter, passing round "Howard" Clip drums attached to winding engine. On these inclines

DIAGRAM. ROPE INCLINES.



the wagons are taken on a carrier built with its top horizontal, having a pair of rails to take the wagon, and suitable clips and fastenings to keep the wagons in place while being lowered.

The gauge of the carrier inclines is 5 feet 6 inches, in order that lateral stability may be insured.

At the top the carrier comes up against a platform (beneath which is fixed the clip drum), so that the rails on the carrier form a continuation of a road ending on the stage front, thus allowing a wagon to be pushed on to the carrier by hand. At the bottom the carrier goes into a pit until the rails similarly coincide with a road, on to which the wagon is pushed off.

The line is a double one, but on the lower side of the middle point the rails overlap so as to save width in the cuttings and to economize sleepers.

From the foot of this lift a temporary line is laid until the permanent alignment is reached at mile 375.

Besides ordinary temporary bridges over the Morendat and Gilgil Rivers no diversions are needed until the 460th mile is reached, but between that point and Mau summit there will be 15 miles of temporary railway with 3 per cent. grades and 14° curves, and with several reverses or zigzags. Between the summit and mile 539 22 miles of diversions are laid out, the steepest grades in this case being as much as 4 per cent., as they will be with the load.

The permanent way used consists of 50 lbs. per yard "Vignoles" pattern steel rails, laid for the most part on steel transverse sleepers of the "pea pod" pattern, with clips punched up out of the solid, and the rails fastened in with a taper steel key. Where much salt is found in the soil creosoted pine sleepers are substituted for the steel.

For details of the permanent way material reference may be made to *Instruction in Military Engineering*, Part VI., *Plate* XX., and *Notes on Permanent Way Material, etc.*, by W. H. Cole.

In the first instance the road has been laid without ballast, as it seems to have been a leading idea with every engineer who advised on the project that ballast would be a luxury. On the first section, across the desert portion, the natural soil, being of a sandy nature, has up to the present answered fairly well, but the black soil between mile 275 and Nairobi turned into a quagmire during the first rainy season after laying, and blocked the traffic for over a month. This was foreseen by all who had had experience of similar country and of tropical rains, and the Chief Engineer had made arrangements to collect ballast for this section in any case. The result of this experience was that the Supervising Committee at home decided to ballast the whole length of the line.

The locomotives built specially for the railway are 6-wheeled coupled, with a load of 10 tons on each axle. Just over one-half of the total number were procured from the Baldwin Company in America, and these have a pony truck (two-wheeled bogie) in front which on the sharper curves is of much advantage, and enables the coupled axles to be kept closer together.

The total number of locomotives on the line is 92, made up as follows :—

Six second-hand shunting engines from India.

Sixteen second-hand 6-wheeled coupled engines with pony trucks, also from India, but of low power.

Thirty-four standard type engines from England.

Thirty-six standard type engines from America.

The particulars of these standard engines are :—

Diameter of cylinder	14½ inches
Length of stroke of piston ...	20 ,,
Diameter of coupled wheels ...	42½ ,,
Firegrate area	13·4 square feet.
Heating surface	766 ,,
Working pressure in boiler ...	160 lbs. per square inch.
Wheel base (rigid)	11 feet.

Tender.

Number of wheels	6.
Diameter ,, ...	25⅜ inches.
Wheel base	7 feet 10½ inches.
Capacity of tank	2,000 gallons.
,, for fuel	180 cubic feet.

The rolling stock has steel underframes in all cases, and the goods stock built for the line is wholly of that metal. The 120 old ballast wagons purchased in India have wooden frames, but these are nearly worn out.

The whole of the stock is fitted with central buffers and the

Norwegian pattern coupling hook, which seems to be stereotyped by English makers, but which is a fruitful source of breakaways during the time the road is rough and unballasted.

Rolling stock consists of

149 passenger vehicles,
3 horse boxes,
25 cattle trucks,
3 powder vans,
60 special water tank wagons,
50 brake vans,
850 goods wagons.

The peculiarities appertaining to this part of Africa have thrown upon the Chief Engineer many duties beyond those which ordinarily fall upon the railway builder. Although it was known that skilled labour did not exist, it was hoped and supposed that the natives would readily take up earthworks, and for over two years every possible effort was made to induce them to labour. On several occasions it seemed as if these efforts would be successful, and at one time as many as 1,700 local men were on the works, but their stay was always fitful, and after a week or two the numbers quickly melted away. Even the pressure of famine, which in 1899 was heavy in the land, failed to make them work—they preferred to die.

Indian labour, therefore, had to be relied on altogether, and although costly, owing to the expenses of importation and repatriation, the Indian navvy has been the only sure workman. The outbreak of plague in India during 1897 was the cause of much delay and great additional trouble and expense, adding considerably to the work of the agent in India.

Transport was another serious undertaking. Many efforts were made to work animal transport in the "tsetse fly" region, as porters were very difficult to obtain in sufficient numbers, but after a loss of nearly 1,500 animals their use had to be abandoned. Towards the end of 1897 the Consulting Engineer recommended the trial of traction engines of an improved pattern, manufactured by Fowler & Co., of Leeds; two were ordered and delivered in March, 1898. After a few months' trial they proved so satisfactory that two more were asked for and sent out, and all of these have done excellent service ever since.

The particulars of these traction engines are as follows:—

The engines are compound.	
Cylinder, H.P.	$6\frac{3}{4}$ inches diameter.
Cylinder, L.P.	$11\frac{1}{2}$,,
Piston stroke	12 ,,
Boiler pressure	180 lbs. per square inch.
Revolutions	150 per minute.
Brake, H.P.	70.
Speeds, fast	5 miles per hour.
Speeds, slow	$2\frac{1}{2}$ miles per hour.
Weight of engine	18 tons 18 cwt.
Fuel, oil tank capacity	50 gallons.
Coal bunker ,, ...	9 cwt.
Water tank ,, ...	400 gallons.
Water in tender	900 ,,

Beyond mile 250 mules and oxen have been employed with success.

The provision of food for the small army of labourers now nearly 20,000 strong is no light undertaking. Flour in large quantities has to be imported from India, but as a check on the suppliers corn mills had to be set up in Kilindini, and wheat is occasionally imported from England.

The amount of bridging to be provided for the passage of maximum floods called for early decision on the part of the Chief Engineer. This question is one of the most difficult matters to determine in any country which has not a long series of rainfall records, and particularly so within the tropics. To the railway engineer the average annual or monthly rainfall is not a matter of so much moment as the maximum fall that may take place in 24 hours, or 6 hours, or 1 hour, depending on the areas affected in each case. Mere inspection of the watercourses is, as a rule, misleading, more especially as the railway works tend to concentrate the flow that would otherwise pass by many small and, in the dry season, unnoticeable channels into the main depressions. Already on this railway there have been several instances of pipe drains being superseded by large culverts, and one in which a drain has been replaced by a girder bridge of 40 feet span. It is very possible, indeed probable, that longer experience of the country will show other weak points necessitating revision of the provision for waterways. Within my own experience I have come across several instances where maximum floods occurred at intervals of from 30 to 50 years. In the case of one of these, where I was fortunate enough to obtain a very precise record of an old flood, the reliability of the information was doubted by those in high authority, and the waterway provided in the design for a bridge was curtailed. Many years after I witnessed a flood in this river which rose 2 feet higher than the level shown by the old record, resulting in considerable damage to a large military station, aggravated by the still further rise caused by the throttling of the river by the bridge so built. The river above the bridge drains an area of over 3,000 square miles, and at several places within that area a rainfall of upwards of 20 inches within 24 hours was registered on this occasion. Over smaller areas the intensity of rainfall is frequently much greater. I have known of a fall equivalent to 4 inches in 50 minutes registered in a basin of 5 square miles.

In another case of a bridge of three spans of 150-foot girders the under side of the girders was at a level of 15 feet above the roadway of an adjacent public road bridge which had been in existence for over 20 years. Both were swept away by a flood, which must have been 20 feet at least above the level of any previously recorded.

During the present year the Rajputana railway in India (a line 25 years old) has been breached in many places by floods, although hitherto it has been considered that the waterways allowed on this line had been excessive.

These instances, out of a very large number on record, show the amount of care and of study of all data and records available, which is necessary in deciding on the openings to be allowed for the passage of flood waters through a railway. It is desirable, however, that over-caution in this respect should not lead to extravagance; neither, on the other hand, should too great a regard for present economy lead to ultimate waste of time and money.

In order to provide for the traffic that may be gathered from the shores of Lake Victoria, and for the distribution of imported goods, steamers will be placed on this inland sea to be worked in communication with the railway. The whole of the material and engines will be prepared in this country ready for erection, and will be forwarded directly the rails reach Port Florence.

The leading dimensions of these vessels will be as follows :—

Length	175 feet.
Breadth	29 feet.
Depth (moulded)	9 feet 6 inches.
Draught (loaded)	6 feet.
Speed	10 knots when loaded.
Cargo capacity	150 tons.

Engines, triple expansion with twin screws.

Supplementary Note on Traffic.

A few remarks on this subject may not be out of place. The railway is opened for public traffic up to the last complete station interval as soon as possible after the rails are laid, generally within a month or two, to the great convenience of travellers and of the Protectorate Authorities. The public traffic, *i.e.*, all traffic not on account of the railway itself, has averaged about £4 per mile per week since the first length of 100 miles was opened in February, 1898.

Stores, troops, and other passengers connected with the Protectorates have been conveyed to the extent of 5,000 tons of stores and 47,000 passengers, including troops. The difference in cost of conveying these by rail as against road transport has up to June, 1900, amounted to about £300,000 ; while during the Soudanese Mutiny in Uganda in 1898 the saving in time in transport of reinforcements just saved the situation.

APPENDIX I.

Summary of Captain Pringle's Description of the Method of Surveying for the Reconnaissance Survey of 1891.

"The daily route was traversed with compass, aneroid barometer, and pedometer, and the plan plotted on the field. The general slopes of the country at right angles to the traverse were observed with Abney s levels. By a combination of these cross sections with the barometer observations the plans were approximately contoured at vertical intervals of 100 feet. A section was at the same time prepared from the barometer readings, corrected as far as possible for the daily wave and for atmospheric changes. These field plans were re-plotted in camp, linked together by triangulation where feasible, and otherwise by astronomical observations, and were amplified by sketching in surrounding country by means of plane tables set up on commanding points.

"The dense nature of the bush and want of time preventing regular triangulation, astronomical observations were made to check the positions occupied at the end of each day's march, one or other of the following methods being used as was found suitable :—

"(*a*). Latitude and azimuth observations to any well-defined point previously fixed to the north or south of the camp.

"(*b*). Latitude and distance observations where the only previously determined points lay east or west of the camp, the distance being determined by measuring a short base, and taking theodolite or sextant observations from either end.

"(*c*). When the above two methods failed, the position of the camp was determined by latitude and longitude observations, the latter depending for their accuracy on the ratings of watch chronometers.

"(*d*). Observations for absolute longitude were taken whenever opportunity occurred of occultations, either of a star by the moon or Jupiter's first satellite, and thereby the ratings of chronometers were checked.

"During halts of 24 hours or over diurnal wave curves were made for each aneroid barometer, and instruments were frequently checked and adjusted. Notes were made during each day's march on the following points:—

"Number and position of all small waterways crossed; breadth, height of banks, high flood marks, nature of soil in bed and banks, slope of bed and depth of water, if any, of all streams of 20 feet in width and upwards; and of the general, physical, and geological features of the country."

APPENDIX II.

Method Employed for Final Survey.

The method adopted for the final survey was the usual one of a theodolite and chain traverse following a route determined by preliminary trial lines. This traverse is levelled over with sights taken at every chain; and, where necessary, frequent cross-sections with the spirit level extending according to circumstances for so much as 400 yards on either side of the traverse are made. By means of the longitudinal section combined with the cross-sections a contoured plan is plotted, with contours at 10-foot vertical intervals.

On this plan in the office a centre line is laid out, and a rough section prepared from the contours; when found satisfactory it is transferred to the ground, and then a final set of levels is taken over it, from which the working section is prepared.

It may be explained that for railway work a transit theodolite is the instrument usually employed, and for measuring a 100-foot chain is used, pickets being driven at every chain length nearly flush with the ground on which levels are taken, as well as intermediate points where necessary.

PLATE I.

ORI
RAI
NCE.
donald, R
INDIAN
OCEAN
4° S.
40°
R. Kilifi
Kilifi
Kurwitu
Kijipoa
Kanding
R. Matapwa
Bibe
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PAPER IX.

RAILWAY CONSTRUCTION.

BY W. W. GRIERSON, ESQ.

WHEN I received an invitation to give a short address on Railway Construction, I was at first in some doubts whether my remarks should be confined to any special or particular points met with in railway works, passing over details which for the most part are familiar to those regularly engaged on practical construction.

I gathered, however, that a general sketch from the commencement of a contract was rather what was desired, and I have endeavoured accordingly to touch on the various operations, throwing in a few observations which may prove of interest.

Following out these remarks I propose to say a few words on the preliminary steps necessary to be taken before Parliamentary powers can be obtained for the construction of a railway, which include the acquisition of land, the lowering, raising, or deviation of public roads, the interference with tidal waters, existing railways and canals, the power to raise capital, issue shares, and ultimately to demand tolls, fares, rates, and charges in connection with the working of the railway.

The general object and direction of the railway being known, considerable information requires to be obtained upon the ground to enable the approximate position of the centre line to be shown on plan, and an accompanying longitudinal section prepared showing the gradients of the line, and the depths of cuttings and banks, and where roads are affected, cross sections indicating the extent of the alterations.

In the early days of railway construction, when the opposition of landowners to railway projection was very strong, this preliminary information was not easily obtained, but at the present day little difficulty is, as a rule, experienced from owners or tenants objecting to the engineers passing over the ground.

A fresh survey is seldom required. The latest 25-inch ordnance maps are generally taken and corrected on the ground to a width on each side of the centre line slightly exceeding the limits of deviation permitted by Act of Parliament. Levels and measurements for the purpose of determining the position of the centre line and preparing an accurate longitudinal section are, of course, always necessary.

A notice of the intention to apply for powers to make the railway, with other information, requires to be published not only in the London, Edinburgh, or Dublin *Gazette*, as the case may be, but in papers serving the district affected, at least once in each of two successive weeks during the month of November. Ordnance maps, plans, sections, and a book of reference giving the names of all landowners, lessees, and occupiers, public bodies, etc., interested in lands within the limits of deviation, require to be deposited at both Houses of Parliament, the office of the Board of Trade, and with the clerks of the several counties and parishes affected.

The limits of deviation it may be mentioned are in the country 100 yards horizontally from the centre line, and 10 yards in town. The vertical limits of deviation in level are 5 feet in the country, and 2 feet in town.

In the case of light railways the same standing orders are applicable, but notices can appear and deposits be made either in May or November.

It may not be out of place to say a few words on the various considerations which influence the selection of the course of the railway.

Two points being known, approximately (at any rate), namely, the point at which the railway starts, and the point at which it terminates, prospect of future traffic, required speed, considerations of economy, and, of course, the natural facilities for construction, will determine the intervening route.

If speed from point to point is the first object, evidently the shortest route consistent with good gradients and flat curves must be arrived at. If, on the other hand, the railway is intended to serve the immediate district through which it passes, the centres of population will affect its course, and where speed is no great object, sharper curves and gradients may economically permit of a route not open to an express line.

An approximate idea of the possible course or courses of the line may be obtained in the first place by a careful study of the 6-inch ordnance maps and the levels as shown by the contour lines, but the exact position has, of course, to be defined by detailed information obtained upon the ground.

As showing the wide difference in the form of construction between a fast through running line and a district serving branch, I will take two instances in the same neighbourhood with which I have been connected.

Firstly, of a short branch line eight miles in length constructed solely to connect a small town with the main line. Speed was no object, there appeared to be little chance of the line being extended so as at a later date to form part of any through route, and the railway was constructed accordingly as cheaply as possible.

The line is single, curves of 12 and 13 chains are frequent. The ruling gradient is 1 in 80, and the cost amounted to about £8,000 a mile.

The second instance is the line with which I am at present connected; its object is almost entirely to obtain the shortest route to South Wales. It passes through a country entirely agricultural, offering no inducements to diverge, from a traffic point of view, through any particular points. Good gradients, good curves, and therefore speed and facility for conveying heavy loads was the object to be attained. There is no curve sharper than one-mile radius, and the ruling gradient is 1 in 300, and it follows not unnaturally that the first cost is considerable, amounting as it does to £40,000 a mile.

In designing a railway it is very important to keep in mind the traffic that will have to be dealt with. A light railway can only be advantageously built where the traffic will be light, and where the traffic will be heavy it pays to go to considerable outlay in the first cost to avoid bad gradients or sharp curves.

To work a railway to its best advantage the whole of the working parts should be in thorough keeping. A light rail means a light engine, and a light engine means light traffic, and only under these circumstances are sharp curves and gradients permissible.

The effect of one bad gradient on an otherwise well laid out line is more far-reaching in its effects than might at first sight appear, and may increase the working expenses to a very unlooked-for extent. Thus, the number of trucks that can be taken up that particular gradient determines the number of trucks that can be conveyed over the remaining section of the line, and as there is a limit to the number of trains that can be run in the 24 hours, the total daily output over the line is diminished accordingly. Every additional train means increased capital in engine, van, and stabling accommodation, increased labour in driver, stoker, and guard, increased coal and water, and increased maintenance; and while it might be assumed that with the more powerful engines constructed of recent years that the difficulty could be got over, this is not so, or only partly so. The refuge sidings are only laid to hold a certain number of trucks, and it is frequently impossible to lengthen them, and to avoid certain delay to fast trains it is not sufficient to lengthen some, all should be lengthened.

Again, a heavier engine may mean great cost in relaying with a heavier rail; and, further, the strength of the couplings to the trucks (which come from all parts) has to be taken into account, and which may not be equal to the strain of an increased load drawn by a more powerful locomotive up a bad gradient. Equally on the downward grade, the wear and tear of the rail caused by powerful brakes is very great, and it is further evident that a locomotive which could on a fair piece of road convey 50 trucks and is reduced to 25 on account of the bad gradient before it, is not working to its proper advantage.

I think I have said enough to suggest that the working parts of a line should be designed in keeping with the traffic to be dealt with, and that bad gradients or bad curves, which tend in the same direction, should not be lightly accepted

No doubt to some extent a bad gradient can be got over by means of banking engines, but there are evident drawbacks. A locomotive on any new line is not now allowed to assist a passenger train up a steep gradient by pushing from the back, though on some of the older constructed lines where the practice has been in force from the first, such as on the Midland Railway at Bromsgrove, and between the South-Western and Great-Western stations at Exeter, assistance in that manner still happens daily. In the case of a goods train it is permissible.

Consequently a banking engine means two delays to a passenger train, one at the bottom and the second at the top of the incline, and one delay to a goods train, namely, at the bottom.

Again, evidently the down grade line is occupied by the bank engine returning, and a further train may be kept at the bottom of the incline waiting for the assistance of the returning bank engine.

No statistical statement to apply generally could be made as to the cost entailed by a gradient necessitating the employment of banking engines, but in order to convey an idea of what the minimum cost would be, I will roughly give the following figures :—

The cost of each engine to a railway company may be put down at £1,000 per year. If this sum be capitalized, it represents say £25,000, and as there must be a bank engine not only for the day, but also for the night, the cost of engine power becomes £50,000. Again, where two engines are employed regularly, it is necessary to have a third relieving engine for hospital purposes.

The banking engine will very likely entail a special signal box at the bottom of the gradient, and also at the top, to permit of the engine getting on to the up grade line at the bottom, and crossing to the down grade line at the top, and this means the wages of two signalmen by day and by night, or four for the 24 hours.

Without going into the cost of the signal boxes, the certain increased cost of maintenance, the possible limitation of traffic over the whole section of the line, etc., etc., it may easily be seen that the least cost entailed by a gradient, necessitating a bank engine, is represented by a capital sum of not less than £70,000 or £80,000, and the question therefore to be considered is whether this or a much larger sum of money cannot be better spent in works to obviate such a requirement.

I will now give a few instances of actual working loads taken from the Severn and Wye Railway :—

Gradient of 1 in 132, length $1\frac{1}{2}$ miles, between Lydney and Severn Bridge stations, working load 320 tons.

Gradient 1 in 50, length 3 miles, working load 120 tons.

Gradient 1 in 40, length $1\frac{1}{2}$ miles, working load 100 tons.

Gradient 1 in 30, length $2\frac{1}{2}$ miles, working load 70 tons.

These loads were in force ten years ago, and are certainly now 30 per cent. lower than modern engines would deal with on a good road.

The following table may be taken as giving the loads up various gradients at the present date :—

Loads and Gradients.

Gradient.	Tender Engine. Weight, 70 tons; Steam Pressure, 150 lbs.; Coal Consumption per mile, 40 to 45 lbs.	Heavy Saddle Tank Engine. Weight, 47 tons; Steam Pressure, 150 lbs.; Coal Consumption per mile, 40 to 45 lbs.
1 in 40	120 Tons.	150 Tons.
1 in 50	180 ,,	210 ,,
1 in 60	210 ,,	240 ,,
1 in 100	295 ,,	325 ,,

On the subject of curves it may safely be said that a minimum radius of 80 chains for a first-class line answers all requirements. This was adopted as the normal curve on the Great Central Railway, though in three cases curves of 20, 40, and 60 chains respectively were used from necessity. The same minimum, viz., 80 chains, has been used on the South Wales and Bristol Direct Railway, except, of course, at the actual junction with the existing lines, where 40 chains radius will be used, and will form, I believe, the flattest curve junctions that have yet been put in.

At the discussion on the Great Central Railway, at the Institute of Civil Engineers, a statement was made by a well-known engineer that he would not hesitate to use 60 chains radius on a first-class line if there was any advantage to be gained thereby. There are many places where trains regularly run round a 40-chain radius at 60 miles an hour with perfect safety; but this necessitates a cant of the outer rail of five inches, and naturally increases the wear and cost of maintenance.

Whereas on unimportant branch lines only slow speed and light loads are required, curves of 12 to 16 chains radius are very usual, but the increased length of railway carriages is daily demonstrating the undesirability of curves as sharp as these, and they are avoided as much as possible. The tendency of the rails to spread is, of course, greatly increased, and the wear on the rails themselves and the tyres of the wheels is much greater.

A reverse or S curve is, of course, always objectionable, and it is usual to get in a length of straight, at least, equal to the length of the train, and twice that length, if possible, between two reverse curves.

The cant of the rail is, of course, important, and varies with the radius of the curve and the rate of speed at which trains are expected to run.

Taking a curve of 20 chains radius, the required cant of the outside rail for a maximum speed of 35 miles per hour is 3 inches, and for 45 miles per hour 5 inches.

For a curve of 40 chains radius the required cant of the outside rail for a maximum speed of 40 miles per hour is $2\frac{1}{4}$ inches, and for 60 miles per hour $5\frac{1}{8}$ inches.

Again, for a curve of 80 chains or one mile radius, the required cant of the outside rail for a maximum speed of 50 miles per hour is $1\frac{3}{4}$ inches, and for 70 miles per hour $3\frac{1}{2}$ inches.

The minimum radius round which an ordinary Great Western Railway engine is allowed to work is about 5 chains, but this occurs only in station yards and approaches to engine sheds.

For passenger service the Board of Trade requires a check rail to be provided for any curve less than 10 chains radius.

The method of locating on the ground the exact points indicated on the plan and section is shown by the following figure :—

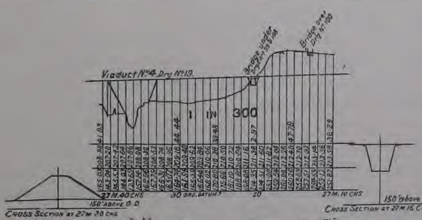


Fig. 1.

The lower part indicates a portion of a plan of the railway, and above the corresponding longitudinal section. Stakes of wood about $1\frac{1}{2}$ inch square and 12 inches long are driven into the ground at intervals of one chain apart, the required position of the stake in the curve or straight being determined by means of a theodolite. Next, a longitudinal section is taken by means of which the ground line is obtained, and it is usual to write up on the section the level of each chain peg, and also the level of the formation, the latter depending on the gradients, and being a matter of calculation.

Cross sections of the ground are next taken at each chain peg, generally for a width of 100 feet on each side, but varying according to circumstances, and on each cross section the height or depth of formation is plotted, and the widths and slopes required drawn in. The cross section at 27M—16C shows cutting, and that at 27M—30C bank. In this way the widths of the land required at each point are known exactly, and also the total quantities of cutting and embankment can be calculated.

The positions of bridges and other works are indicated on the plan or section, together with a note referring to the number of the drawing showing the design in detail.

It is not often that a railway company in this country carries out its own work when of any size; to do so regularly would practically mean keeping a separate staff and plant, which might be sufficiently large one year, and altogether beyond the requirements the next. Moreover, the system in force on large railways for the supply of materials would undoubtedly handicap a railway company in carrying out large works.

That system necessitates a railway officer requiring material for any purpose, say 1,000 tons of rails or an office carpet, putting forward a requisition, which, after being signed by the chief of his department, is passed on to the stores department, who order and supply every article, even down to a nail. This system answers very well for maintenance purposes where requirements can be seen in front, and where also the materials for the most part can be kept in large quantities in stock; but on new works where the requirements vary, and where any delay might entail great loss of time and expense, it is essential that the person directly responsible should be in touch with the manufacturers, and be empowered to negotiate and purchase at the shortest notice in the most advantageous market. This difficulty could be got over by special regulations applying to new works, but it is easily understandable that two systems on the same concern are open to some objection. Consequently, almost invariably, works of any size are let by contract.

There are two forms of contract, viz. :—

(1). Generally known as a lump-sum contract, in which the contractor undertakes to complete the whole of the work in accordance with the plans, drawings, sections, etc., for a total sum of money.

(2). A schedule contract, in which the contractor undertakes to carry out the work in accordance with prices inserted in a schedule for each particular item of work, all of which has consequently to be measured as the work proceeds.

The lump-sum contract is generally preferred as being more comprehensive, and tending to avoid the many questions which generally arise in a schedule contract, as to the class of work that is being carried out, and as to the item in the schedule that applies and so on.

The advantage, however, of the schedule contract is that where time is an object, and it is desired to commence the work as soon as possible, it permits of a contract being let after a few typical drawings only have been prepared, whereas in a lump-sum contract the whole of the drawings and every information must first be furnished.

In the case of a large contract this saving of time is often considerable. On the South Wales and Bristol Direct Railway there are something like 100 bridges, necessitating, of course, 100 separate drawings, consisting in some cases of two or three sheets each. There are 2,700 cross-sections of earthwork, and in addition, of course, much detailed information to be supplied to the contractor on a very large number of points, necessitating negotiations with landowners, tenants, public authorities, etc., and consuming, therefore, much time. For this reason the contract to which I have referred has been let by schedule.

The plant necessary to construct a work of this size is necessarily very large, and its value estimated at £100,000. It includes 66 miles of temporary road, 45 locomotives, 17 steam navvies, 1,800 earth wagons, and, of course, numerous mortar mills, winding engines, etc., etc., and also three large brickyards specially constructed.

I need not point out that water in large quantities is a necessity, and the facilities for obtaining it are a matter of much consideration to the contractor.

A railway generally commences with earthwork operations, and I will say a few words, therefore, on the slopes adopted, the question of slips, and some modes of dealing with them.

In clay the slopes vary from 2 to 1 to 5 to 1, and for the most part the same slope is adopted for embankment as cutting. Slopes of 2 to 1 and 3 to 1 are common, but my own experience has been that it is advisable in the case of clay embankments over, say, 20 feet in height, to form them with slopes of not less than $2\frac{1}{2}$ or 3 to 1. The reason that this applies especially to embankments is that in bad weather the excavation may come wet from the cutting, and tend to cause slips.

A yellow clay is generally weak and treacherous, and where it was met with on the line between Wootton Bassett and Patchway a particularly bad slip occurred, necessitating the adoption of the unusually flat slope of 5 to 1.

In material other than clay, but not rock, slopes of $1\frac{1}{2}$ to 1 are almost always adopted, and are certainly the most usual, and in the case of rock the angle for cuttings may be anything from vertical to $1\frac{1}{2}$ to 1, but it has to be remembered that in deep rock cuttings it is well not to make the slopes too vertical, as there is always the possibility of a piece of rock which has weathered loose escaping detection, and the risk, therefore, of its falling on to the railway or a passing train.

On the Wootton Bassett and Patchway Railway the slopes are :—

In Oxford blue clay, 2 to 1 and 3 to 1.

In Oxford yellow clay, 5 to 1.

In lias clay in which there are regular belts of rock at few feet intervals, $1\frac{1}{2}$ to 1.

In marl, $1\frac{1}{2}$ to 1.

In oolitic rock, $\frac{1}{4}$ to 1 in shallow cuttings, and 1 to 1 in cuttings over 20 feet in depth.

In a pennant rock cutting 40 feet in depth, where the stone is tolerably solid and in large beds, $\frac{1}{2}$ to 1.

In mountain limestone, $\frac{1}{2}$ to 1, and where beds of clay occur in it, $1\frac{1}{2}$ to 1.

Prior to the plans being prepared Pits, say 6 feet by 6 feet, are generally sunk at intervals along the centre line of the railway, to enable an opinion to be formed as to the necessary slopes to be allowed for. The quarries in the district also act as a guide.

It should be remembered, however, that the slope depends not only on the material in which it is formed, but also on certain local circumstances. Not unfrequently, for instance, the ground is falling more or less sharply across the railway at right angles to it, and, consequently, water may attack one side of the cutting, while the other side will be quite dry.

In a case of this kind the slope on the wet side may be flattened, and trenches cut, say, 5 feet by 4 feet, and filled with stone. These act as a means of draining off the water, and at the same time as buttresses.*

It is desirable to soil and sow all clay slopes as soon as possible, as that course offers a great protection, and also prevents the constant dribbling of mud into the railway side drain.

Frequently in the oolitic formation water finds its way to the face of the slope at the base of the shale where it joins the clay, and this, if allowed to run, would in course of time naturally eat away the clay and let in the rock above it.

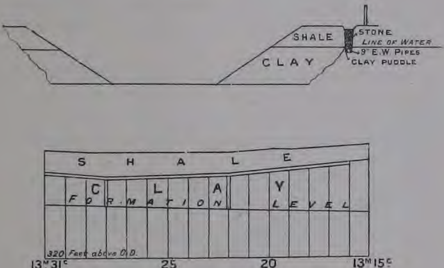


Fig. 2.

This is often dealt with by sinking a trench, as shown in *Fig.* 2, about 12 or 15 feet away from the top of the slope, the further the better, running parallel to the railway. The bottom of the trench is below the rock, and acts as a trap to catch the water. The trench, of course, is constructed with a fall, and is emptied at certain convenient points into the cutting drains.

Slips.

Few railways are constructed, except in uniformly hard material, without some slips occurring in the cutting or embankment, which frequently give great trouble before they are cured, and are the source of considerable delay and expense. This may be due to one or more of many causes.

* This arrangement is shown in *Fig.* 7, Paper V., of this volume.—Editor.

The material may be of so weak a nature that in an extreme case it is absolutely unable to bear its own weight. An instance of this occurred recently in Cardiganshire through a clay in the Cambrian formation. The cutting is about half-a-mile in length, and work commenced in the summer when the material was dry, and stood capitally both in cutting and bank; but as soon as wet weather arrived the sides of the cutting came in, and the embankment formed from the cutting material collapsed. Several expedients were tried to make the bank stand—the slopes were pitched all over with stone 18 inches thick, stone buttresses were erected up the slopes at frequent intervals, and the natural seat of the embankment was drained thoroughly, but without success, and the whole material had to be run to spoil.

To get through the cutting was, of course, a necessity, and this was attained by constructing heavy slag walls 6 feet high and 6 feet thick at the toe of the slope, by benching back the slopes as shown in *Fig.* 3 to reduce the weight and pitching them 18 inches thick.

Fig. 3.

Stone trenches 4 feet by 2 feet were constructed up the slopes to drain the water and act as an additional support. The chief use of the pitching in this case was that it prevented the heat of the sun cracking the sides of the slopes, thereby causing fissures, through which water penetrated in the wet season; the pitching acted also as a protection against frost.

Another case of material too weak to bear its own weight is the yellow clay at Wootton Bassett, where a serious slip occurred. Here the whole of this clay had to be run to spoil, and the slopes of the cutting were left, as before described, at an angle of 5 to 1.

In cutting, slips can generally be got over by careful drainage, to prevent any water forming at the back, by benching the slopes so as to lighten them, and by sufficiently flat angles.

Sometimes on sidelong ground a regular landslip will occur, the ground to some hundreds of yards from the cutting moving towards it. Such a case presents great difficulties and occurred on the Stert and Westbury Railway opened by the Great Western Railway

Company this summer. Here the formation is green sand. When the ground first began to move stone buttresses were built into the cutting slopes, both for the purpose of lending strength to resist the forward movement and to drain the ground. They were found, however, to be quite ineffective, and the cutting was in constant danger of being filled. At the back the ground rises rapidly, and from a careful inspection the conclusion was arrived at that the slip was due probably to water forming there, and to underground springs at that point.

Headings 7 feet by 7 feet were consequently driven at right angles to the railway at intervals of about 3 chains, extending from the cutting to points below the foot of the steep rising ground just referred to.

Section at right angles to Railway.

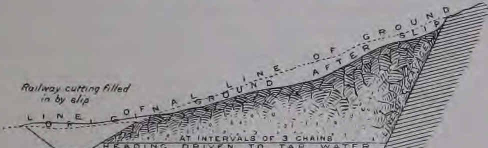


Fig. 4.

The section (*Fig.* 4) at right angles to the railway explains this; the dotted line represents the original surface of the ground, and the firm line the ground after the slip occurred showing the cutting filled in. The heading is shown extending from the cutting to the line of cleavage, that is the furthest point of the slip. The extreme ends of the headings were connected by another continuous heading running parallel to the railway, constructed with slightly rising and falling gradients, so as to drain the water to the exits in the cutting. No further slips have since occurred, but the success of the scheme cannot be assured until tested by the coming winter. The headings will be finally filled in with big loose stone.

In embankments slips may be caused, apart from the material being too weak to bear the superincumbent weight, through the natural surface of the ground being soft or wet—in which case it should be thoroughly drained by stone channels and the soft stuff removed, or by tipping into the embankment wet excavation or slurry—or by want of care in the formation of an embankment when formed in two or more lifts.

Fig. 5 shows coarsely hatched the bottom portion of an embankment formed in two lifts. Great care should be taken to ensure that it is formed in the first case to its full width, so that when the top lift comes to be tipped there will be no narrow width to be patched on to the lower portion as shown by the figure on the right side.

Strengthened Embankment.

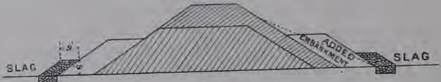


Fig. 5.

This particular embankment showed signs of weakness, and it was decided to strengthen it by added embankment and a stone toe. For the purpose of construction it was necessary to tip to a level surface the added embankment, which afterwards was trimmed down to a uniform slope, as shown by the dotted line, to prevent water lodging and getting into the earthwork.

The added embankment will, of course, not be confused with the narrow width patched on, as referred to above, due to improper construction.

As far as possible an embankment should be formed with end-tip wagons, and not side-tip wagons, the effect of the side-tip wagons being that the grain of the earthwork, so to speak, runs parallel with the embankment and not across it. Further, in the case of end-tip wagons the portion tipped is subsequently passed over by the temporary road, and gets, therefore, the weight of the engine and earth wagons, which tends to consolidate it. In the case of side-tip wagons this is not necessarily the case.

These remarks perhaps do not properly apply to the formation of the bottom lift of a deep embankment, where by the use of side wagons and the continual slewing of the contractor roads sideways as the width of the embankment increases, the whole surface at one time or another receives the weight of the wagons, etc., and is to some extent consolidated.

Of course, there is a great advantage in side wagons in economy and expedition in getting rid of material into embankment. Considerable difference of opinion was expressed at a recent discussion on the merits of side as against end-tip wagons at the Institution of Civil Engineers. So far as an embankment for a single line of railway was concerned, it appeared to be agreed that there could be no question, and that end-tip wagons were evidently indicated for such work, but for wider embankments there was considerable divergence of opinion.

Again, a bottom lift may frequently pass through a winter before the top lift comes to be formed upon it, and great care should be taken to leave the surface in such condition that water will not form in hollows, and ultimately penetrate the bank in considerable quantities. The surface should, therefore, be left smooth and slightly cambered, and all cracks filled in, and before the top lift is formed any soft material should be moved from the surface.

Two years since a high railway embankment at Chippenham, which had been constructed over 50 years, began to slip. A series of trenches were consequently cut right from the surface of the embankment to the ground level, with the result that the bank was found to consist internally of a reservoir of water, and when this had escaped no further trouble occurred.

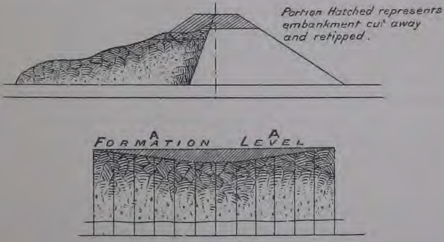


Fig. 6.

In slips of a serious nature the top of the embankment may be cut down, as *Fig.* 6 will explain, and this is a very desirable course. The lower part of the diagram represents a longitudinal section of the embankment, the slips having occurred between the points AA. The whole of the material shown hatched may be removed, and the object of this is made more clear by the cross-section.

An embankment after a slip on one side only consists practically of two distinct parts, the stable portion in this case on the right, divided by a fine line from the slipped portion shown by darker colour on the left.

If an attempt is made after a slip to make good the embankment to its proper height without first cutting away the top part as shown by longitudinal section, the embankment remains practically in two distinct parts, there is, so to speak, no bond in it, but by cutting it down and then making good by re-tipping, the top portion of the bank forms one mass as shown hatched, resting partly on the solid and partly on the weaker or slipped portion.

Plate I. shows a steam navvy. The engines are generally 8 to 12 horse-power, worked at 70 to 80 lb. steam pressure, consuming about 15 cwt. coal per diem.

Twenty men, including batter trimmers, are employed attending on and working round the navvy, or 15 men where there are no batters to form. In addition, two horses and two men are required to feed the navvy with empty wagons, and to remove the full ones. If the output, however, exceeds 200 wagons per day three horses and three men are required. The bucket varies in size, and for rock has generally a capacity of one cubic yard. In soft material the capacity may be increased to two cubic yards. In fine weather and in good material it will move about 600 cubic yards per day. It is not necessary to add that, apart from rapidity and economy, they are of the greatest use where hand labour is short.

A steam navvy costs £1,200, its carriage is considerable, and the cost of erecting on the ground about £20; consequently it would not pay to use them where the material to be moved is not considerable. A steam navvy will work in soft rock, but it is, of course, essential to shatter and disintegrate the rock by means of explosives.

Where belts of rock occur in a clay formation considerable quantities of blasting powder are used. The charge is generally inserted some 20 feet in advance of the steam navvy. A hole is first sunk by means of a drill the required depth, maybe 20 feet, and a charge of tonite exploded, say up to 15 lb., to form a cavity at the base, into which the powder is charged. As much as 600 lbs. at a charge have been used in stiff clay ground.

In India, where the conditions are different, the excavation is still carried to a great extent in baskets on the coolies' heads.

The best method of removing excavation to embankment depends on several circumstances, such as the length of lead, the total quantity of material to be moved, etc., etc. Up to 80 or 100 yards an ordinary barrow or hand-cart may be used, but the latter is only suitable on fairly level ground, as when loaded its weight would be beyond the powers of a man to push up any steep incline. For longer distances a horse and dobbin cart, horse and tip wagons, or locomotive and tip wagons may be employed.

I need hardly add that on any length of railway a good temporary road is absolutely essential for the conveyance of material, such as coal, bricks, lime, mortar, stone, water, etc.

I will now make a few remarks on the class of structures met with in railway work, and perhaps I should first say that an efficient system of drainage by means of side ditches, trenches, pipes, and culverts is of the greatest importance, and tends greatly to reduce the after cost of maintenance.

A culvert hardly requires describing. It invariably consists of an invert of concrete with stone or brick walls, as a rule 14 inches or 18 inches thick, and an arch not less than 9 inches. It is well to remember, however, that in the case of a high embankment, and especially where the arch and possibly the walls of the culvert project some distance above the natural surface of the ground, that the pressure and weight exerted by the bank is very considerable, and that therefore in such cases it is always wise to considerably strengthen the culvert, as, in the event of damage, it is a matter of great difficulty and expense to re-build it after the embankment has once been formed.

Coming to bridges, the first question that arises is the question of brick or masonry, and depends almost entirely on the presence of a good building stone material in the country. From the point of appearance stone is preferable, and given a good quality is extremely durable. It is also generally cheaper for the class of work required on a railway than brick. Of late years, however, since railway transit has become much more general, and has placed Staffordshire in touch with every point, brick has been used to a much greater extent than formerly. Again, the frequent labour troubles that have arisen of late years with quarrymen, masons, dressers, etc., causing most troublesome and expensive delays, have led to the greater use of bricks.

The class of brickwork on railways now is almost invariably required to consist of good local bricks, faced to an average thickness of 6¾ inches, with Staffordshire brindles. Work of this class practically means no future maintenance, as a good Staffordshire brindle, in addition to being able to resist a great pressure, is imperishable by weather, and is not affected by injurious gases such as are met with in a tunnel.

Results of Brick Tests Made 1900.

	Tons Per Square Foot.		Porosity after 24 Hours Immersion. Per Cent.
	Cracked Slightly.	Crushed.	
South Staffordshire Brindle	427	481	1·48
Cattybrook Brindle	412	546	0·42
Stoke Gifford Brindle	307	524	0·23
Hamblet's Staffordshire Brindle ...	402	523	1·59

The mortar generally consists of blue lias lime, in the proportion of 1 of sand, 1 of ashes, and 1 of lime. Tests of the mortar are generally taken from time to time, a briquette being made for that purpose 1 inch square in area at the least section, and tested at the end of 28 days.

The results vary very considerably, and depend no doubt to a large extent on the method employed in making the briquette. For instance, if the mortar is first placed on a porous brick, and worked with a trowel, it has the effect of withdrawing the water and causing the briquette to set more rapidly; uniformity of method in making the briquettes should, therefore, be in force. The results vary from 30 to 80 lbs. to the square inch, and if as an average 50 lb. is obtained the result may be considered satisfactory. The arch form of bridge is always to be preferred to ironwork, on the grounds that the latter requires constant maintenance, and has a limited life, while a good brick or masonry bridge requires practically no maintenance, and should last for ever. The largest arch in England is that over the River Dee, at Chester; the span is 200 feet, with a rise of 42 feet, the arch being four feet thick in the centre, and six feet thick at springing. Another large arch is that over the River Severn, at Gloucester; it is 150 feet in span and elliptical in form. I am not acquainted with the details of the thickness of the arch, etc.

The largest bridge of this kind on the Great Western Railway is that over the River Thames at Maidenhead; it consists of two arches, elliptical in form, and 126 feet each in span, the rise being 24 feet 3 inches. The arch, which at the centre is 5 feet 3 inches thick, and at the springing 7 feet $1\frac{1}{2}$ inches, was constructed by Brunel of London stock yellow bricks in cement, the thrust being 12 tons per square foot at the centre, and $10\frac{1}{2}$ tons at springing. The bridge was widened some ten years ago, the arch being built with Cattybrook pressed bricks in cement. It was found that the true lines of the arch of the old bridge were considerably distorted, and this no doubt occurred at the time of construction due to settlement.

On the South Wales and Bristol Direct Railway the largest arch is 76 feet in span, with a rise of 16 feet 9 inches; the arch at the centre is 3 feet in thickness, and at the springing 4 feet $1\frac{1}{2}$ inches, the pressure at the crown being 8 tons per square foot, and at the springing $7\frac{1}{2}$ tons. The arch is built with Staffordshire brindles and cement mortar, and springs from a pennant rock foundation, the pressure on which is 4 tons per square foot.

Any contraction of the foundations might cause distortion, and it is essential, therefore, that arches of this type should butt on a thoroughly sound foundation, which is generally restricted for this purpose to rock.

The span of an arch is limited by the safe resisting power of the material, which on the Great Western Railway is taken as 15 tons per square foot in blue brickwork in cement, and 8 tons in mortar, and by the strength of the foundations. In rock about 16 tons per square foot is generally taken as the maximum, and in clay 4 or 5 tons. In the case of the Great Central Goods Warehouse at Marylebone, where the foundations are in the brown London clay, 4 tons were taken as the maximum.

In the case of London Bridge there is a pressure of 5 tons per super foot on the foundation.

You may, of course, thicken your arch almost indefinitely, and to a certain extent by means of vertical headers bond the various rings together. But in taking down old bridges it is nearly always found that, due to settlement, the lowest rings do the lion's share of the work.

It is evident then that the span of an arch is limited by the strength of material, and an arch of 100 feet span may be considered a large one; but in much smaller structures there are reasons why ironwork must constantly take the place of the arch.

Fig. 7 shows a bridge carrying a road over a double line railway. The minimum depth from rail to underside of girder must be 14 feet 3 inches, and assuming a trough flooring 9 inches in depth, with upon the flooring by the moving load it is assumed that the weight on the driving wheels, which is taken as 10 tons on each wheel, is distributed over 7 feet of flooring, thus if each of the flutes were 12 inches in width, each flute would be calculated to bear one-seventh of the total weight on the driving wheels.

Where no girders are used the flutes of the flooring run parallel to the rails, and, consequently, cross-sleepers are used, the load in this case being assumed as distributed over the length covered by the sleepers, viz., 9 feet.

To bring structural depth to its lowest limits the cross-sleepers are sometimes sunk into the furrows of the flooring, or the rail may be attached direct to the top of the flooring by continuous angle fish-plates. The effect on the distribution of the load requires, however, to be carefully considered, as the probabilities are that the flooring will, under such conditions, require to be considerably strengthened.

Another means of constructing with the minimum depth is by carrying the rail in a trough consisting of two steel joists bolted together at the bottom by a steel plate; this method, however, is only applicable to spans not much exceeding 15 feet.

Where headroom permits, an economical and substantial superstructure is obtained by the use of rolled steel joists about 3 feet 3 inches apart, connected by $4\frac{1}{2}$-inch brick jack arches filled into the surface with cement concrete. It is particularly useful where an absolutely water-tight structure is required.

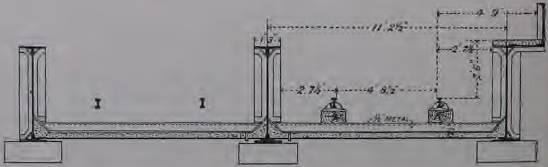


Fig. 9.

Fig. 9 shows a common form of bridge to carry two lines of way, which takes advantage of the Board of Trade regulations—which permit a structure standing not more than 2 feet 6 inches above rail level—to come within 2 feet $7\frac{1}{2}$ inches of the near rail.

The parapet is overhung to comply with the required width of

4 feet 9 inches above that level, and the top of the girder is boarded over so as to form a platform. The flooring is commonly $7\frac{1}{2}$ or 8 inches in depth, with metal $\frac{1}{2}$ inch thick.

The cost of different forms of steel structures varies considerably, and I will only say that the trough flooring type of bridge, including concrete, asphalte, steel parapets, in fact, everything except ballast or metalling, costs, for small spans up to 15 feet, about 10s. per super foot at present prices; spans up to 25 feet will cost from 10s. to 12s 6d. per super foot. The cost of the jack arch type of bridge just referred to is also about 10s. per super foot. Above 25 feet in span the cost increases rapidly, owing to the weight of girders increasing approximately as the square of the span.

Before leaving steelwork I should say that I mentioned just now that an arch, where feasible, was always preferable to an iron superstructure. I ought to say that in a very doubtful foundation this is not the case. In the Black Country, for instance, settlement is continually taking place, and under these conditions an arch is evidently unsuitable.

A case occurred on the Great Western Railway in the Forest of Dean recently where a bridge in the course of two years sank to the extent of 2 feet 6 inches, necessitating the raising of the girders from time to time to that extent.

On the Great Central Railway steel superstructures were solely used on one section, due to the proximity of the coal workings, and in one case the abutments of a bridge sank as much as 3 feet after its completion. Partly, no doubt, due to this consideration 155 bridges on the Great Central Railway, out of a total of 224, have steel superstructures, an unusually large proportion.

The erection of small girders is a simple matter. They are generally sent from the manufacturer in one piece, and erected by means of cranes, derricks, etc. Where, however, the length approximates 100 feet there is difficulty in sending them by rail, and consequently they are generally made in two parts and erected by staging on the ground.

Fig. 10 shows the method to be shortly employed in erecting two girders 88 feet in length, each weighing 21 tons, over an existing line of railway. The wooden staging on either side of the railway will be erected during the week; occupation on the line will be obtained between the hours of 10 a.m. and 5 p.m. on a Sunday (during which time no passenger trains are booked to run), and the centre trestle and baulks to the centre span erected. The girders

G. W. R., South Wales and Bristol direct Railway.—Bridge over Midland Railway. Proposed method for erecting girders.

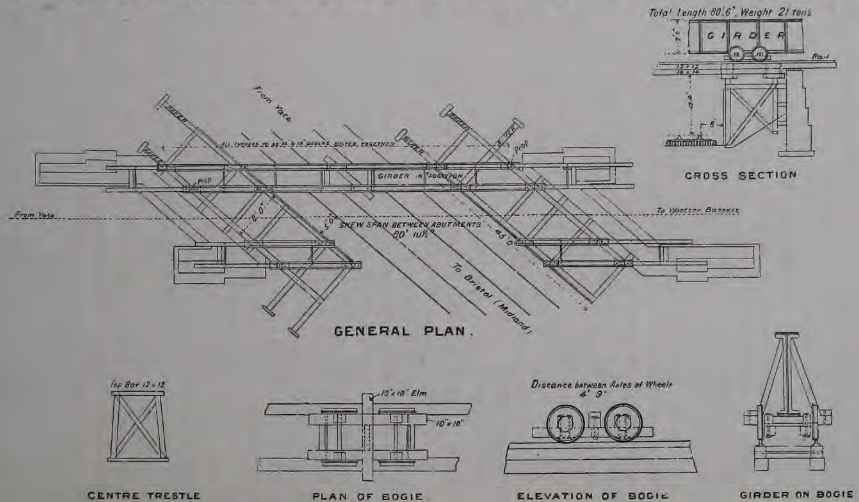


Fig. 10.

will have been previously placed in readiness to be drawn over, each supported on the trolleys, and as soon as the temporary structure is ready they will be hauled over their permanent position by means of a 5-ton steam winch. They will then be jacked up sufficiently to allow the trolleys to be run from under them, and afterwards by the same means lowered on to the bedstones.

In another method of erecting girders of practically the same size, 90 feet in span and weighing 25 tons, the girders were conveyed to the bridge along the main line on trucks, and raised by means of a derrick, the chain from the snatchblock being attached to an ordinary locomotive, which, by moving backwards, raised the girders into the required height.

Plate II. illustrates the general form of centering employed for the support of arches under construction. These frequently vary in design for the same type of arch owing to local circumstances, such as the depth of headroom, and the necessity in some cases of keeping open traffic beneath the bridge while under construction. This plate shows centering for a bridge 35 feet in span, where there is ample headroom and plenty of space for a temporary roadway on one side of the centre props.

The laggings on which the brickwork is built are almost invariably $2\frac{1}{2}$ to 3 inches thick and from 6 inches to 9 inches in width, according to the radius of the curvature, and are supported by ribs placed generally about 5 feet apart centre to centre.

An arch to carry two lines of way, or a public road 25 feet in width, requires 6 ribs. This is not an invariable rule, ribs sometimes being placed as much as 7 feet apart, but where this is the case there is a tendency of the laggings to sag, and the true lines of the arch to be distorted. Each rib rests on a pair of slack blocks or wedges, by means of which the rib can, in the first place, be adjusted to its exact position, and slackened when required after the completion of the arch. The slack blocks rest on a continuous wooden cill supported either by props direct from the ground, or, where the height is great, by byats passing through the piers, as will be seen by a later photo. The sweeps, as they are termed, forming the rib, consist almost invariably of pitch pine, the tie-pieces, struts, and laggings generally of fir, and the slack blocks of oak or some other hard-grained wood.

Plate III. shows the centering for a viaduct consisting of 11 spans 25 feet in width of an average height of 33 feet from ground to rail level, the arches being practically, though not quite, semi-circular.

In the case of viaducts of large spans 5 sets of centering are universally used, but in the present instance, where the arches are only 25 feet, and the height not great, 4 sets only were used.

The plate shows the arches over the 4 sets of centering built to different heights, the left-hand arch being nearly finished, the second rather more than half, and the third less again, and the fourth only just commenced.

The reason, of course, is to distribute the uneven thrust, which, if one arch were wholly built before the next was commenced, would be sufficient to overturn the piers. The struts shown in the plate are to assist in counterbalancing this thrust. The centering in this case is supported on a wooden cill resting on short lengths of rail passing through the piers.

Perhaps the most usual method of building viaduct piers is by the employment of two cranes, one fixed between, say, piers 1 and 2, and the second between piers 3 and 4.

The cranes may be raised on a staging above the ground to such a height as will command not only the foundations, but also the impost or top of the piers. In this way material from the foundations can be removed in skips, and afterwards the whole of the pier built by lifting direct from trucks at ground level into its position material required for their construction.

The centering may be raised and placed in position by derricks, and a small tramway or gantry may be carried on the centering for the supply of material when the arches are being built.

Each set of 6 ribs and laggings, etc. (for a span of 58 feet), contains about 1,500 cubic feet of timber, and cost for material and making about £130; the cost of erecting and taking down amounts to £30, or a total of £160. Crediting the value of the material after use at £50, the actual cost of one set of centering becomes £110, which, if divided into the number of yards of brickwork in the arch, in this case 310, gives the extra cost of these arches due to centering as 7s. 1½d. per cubic yard.

Frequently, however, the centres can be used and re-used several times where the viaducts consist of many spans, or where there are a series of viaducts of the same span. On the South Wales and Bristol Direct Line there are 19 similar spans, and as 5 centres are required at the same time, each centre will be used 4 times, and, consequently, the cost of centering per cubic yard of brickwork in arch is reduced to about 3s. 3d.

Viaducts are generally built in lieu of earthwork where the depth exceeds 50 or 60 feet. As far as economy goes, the actual depth varies, of course, according to the cost of embankment material and the slopes at which it will stand, it being evident that an embankment with 2 to 1 slopes might be cheaper than a viaduct, and more expensive if 3 to 1 slopes were necessary.

Apart from cost, however, a bank over 50 feet is a high one, and the material of which it is formed, and the natural surface of the ground on which it rests, should be good; and, further, future maintenance, which in the case of very deep embankments is great, has to be taken into consideration.

On the Great Western Railway there are a great many viaducts, especially in Cornwall, commencing at 50 to 60 feet deep, and being as much as 90 or 100 feet, and even up to 150 feet, in the centre of gorge. They are, as a rule, about 60 feet spans between the piers, which is found to be the economical width. Segmental arches nearly but not quite semicircular, 3 feet in thickness at the centre, and 3 feet 9 inches at the springing. Piers 7 feet 6 inches wide at the top, tapering on every side at 1 in 32. This gives a pressure of about 8 tons per square foot on the masonry. The cost comes out for such a structure carrying two lines of way at £1 per yard forward per foot high, measured from ground to rail. That is, for example, a viaduct 200 yards long, and averaging 70 feet in depth, will cost £14,000.

We have two tunnels on the line I am at present connected with, one about 560 yards in length and the other 2½ miles, both on a uniform grade in one direction of 1 in 300.

The St. Gothard, Monte Cenis, and Simplon tunnels, where the headings could only be driven from the open ends, are constructed with gradients ascending from each end towards the centre, the chief object being to enable the water to escape by gravitation, and where the levels admit this practice is frequently adopted in much smaller structures. Where, however, the tunnel is constructed by sinking shafts the advantage is largely done away with, as pumping in the various headings is a necessity until they are connected with the open ends.

The first of the 2 tunnels mentioned above is being constructed from 2 shafts sunk 280 yards apart, and 140 yards from each open end. Work is only carried on during the daytime, and the progress made is 6 yards per month to each working face, and as there are 2 working faces from each shaft, or 4 in all, the progress in the tunnel is 24 yards per month, or rather less than 300 yards per year. No continuous heading has been driven, length after length of excavation being removed and the brickwork built in. The tunnel is in the great oolite, which consists of a fairly hard yellow limestone up to the springing level, and a blue clay above, and is almost entirely free from water. There is no invert; the walls are 1 foot 6 inches thick, and the arch 1 foot $10\frac{1}{2}$ inches. No rock drills are used, the excavation being carried on entirely by hand, the total cost amounting to £56 per yard forward.

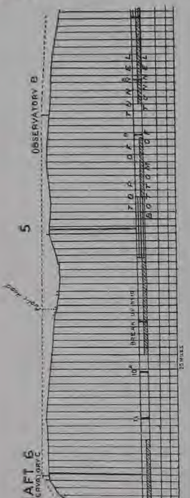


Fig. 11.

Fig. 11 shows a section of part of the second tunnel, which is $2\frac{1}{2}$ miles in length. There are 7 shafts situated as shown on the plan at distances apart varying from 440 yards to 800 yards, the position of the shafts being regulated by an agreement with the landowners before the Act of Parliament was obtained. The tunnel passes through the Cotswold Hills, and strikes at the west end the lower lias formation, and passes through the upper lias, emerging at the east end at the base of the forest marble.

The depths of the shafts vary from 80 feet to 270 feet. Observatories are erected at three points, as shown on the diagram, commanding between them a view of the whole length of the tunnel, which is straight throughout. The observatories consist merely of brick pillars built exactly over the centre line. On the top of each pillar the metal stand of a theodolite with sliding movement is built in, and the telescope, which is 24 inches in length, is carried from observatory to observatory as required. A wooden platform covered in and supported direct from the ground is built round the top of each pillar, but not touching it, on account of the vibration caused by wind.

The operation of setting out the lines with headings is, shortly, as follows, viz. :—The centre line having been accurately set out on the surface of the ground, which often can only be done after the observatories have been built in approximately their right positions, the true centre is marked on each of the brick pillars, and the telescope is set up, say, at observatory C. After the usual adjustments to ensure that the instrument when turned vertically on its axis will strike the centre marked on the observatory at B, and some other central point in the opposite direction, and is, therefore, in its true line, a point D is set out at a convenient distance from the shaft, say, 20 or 30 feet. A wooden plug is generally used for the purpose, driven into the ground, and a tin tack inserted to denote the exact central point.

A 5 or 6-inch theodolite is then set up on this point, and carefully adjusted until the instrument strikes the centre on the observatory at C, and some other centre point when reversed in the opposite direction.

Two plough steel piano wires 27 B.W.G. and ·016 inches diameter are next lowered down the shafts by means of jack rolls as far apart as the diameter of the shaft will permit, in this case about 9 feet, with weights attached, each 32 lbs., resting at the bottom in two buckets of water. By means of the theodolite at D these two wires are ranged exactly in the true line.

A second theodolite, also 5 or 6-inch, is then set up in the heading below, say, at a distance of 20 or 30 feet from the wires, and must be shifted about until only one wire can be detected through the telescope, which is then in its true line, and can be used for setting out further points as required.

Where the tunnel is curved the operation is the same, but in this case the wires must represent points in a tangent line, and the process is rather more tedious.

Given a level at which the tunnel is to be constructed, and its exact course, the actual length is decided by the depth of the ground at either end, and, speaking generally, it is economical to commence tunnelling when a cutting reaches 60 feet in depth; as regards this latter point, however, the probable length of the tunnel has to be taken into account, for it has to be remembered that the two entrances to a tunnel are expensive extras. A tunnel entrance in a cutting with slopes of $1\frac{1}{2}$ to 1 costs about £800. Two entrances, therefore, would cost £1,600, and, accordingly, in the case of a tunnel 100 yards in length, the cost of the entrances add £16 to the nominal cost per yard forward. If the tunnel were 1,600 yards in length, the additional cost due to the faces becomes only £1 per yard forward. My point, therefore, is that though the barrel of a tunnel per yard forward is generally as cheap as a cutting 60 feet in depth, it is not always economical to construct a short tunnel in lieu of a short cutting, inasmuch as the two faces add materially to the cost. If the slopes of the cutting were only $\frac{1}{2}$ to 1, say, in rock, the cost of the entrances is, of course, much less.

The position and length of the tunnel being decided, the first point to be determined is the method to be adopted in its construction, *i.e.*, whether by shafts, and if so by what number, and this will depend upon several considerations, viz.:—

(1). The natural lie of the ground, as, for instance, in the case of the Great Alpine tunnels it was evidently impracticable to sink shafts through a mountain, and the Monte Cenis, St. Gothard, and Simplon tunnels were driven, therefore, from the two ends only.

(2). Considerations for the landowners' interests. Shafts may be quite practicable, but the spoil heaps which they entail may be extremely objectionable to the landowners, and their number and position therefore a matter of arrangement. It is evident, too, there must be some means of access to them, either by a cart road or overland route.

(3). The time available for the construction of the tunnel. A tunnel may be a comparatively short one, and yet occur at a point where it acts as a barrier or impediment to the construction of the railway on one side of it, and its rapid completion, therefore, a matter of great importance, and thus a number of shafts may be desirable in one case and not in another.

(4). The excavation from the tunnel may be required to make good the embankments, in which case there is an evident advantage in working as much as possible from the open ends.

(5). Ventilation during and after construction.

(6). The greater the number of the shafts the shorter the distance to the various exits below, and the more economical therefore for working; but, on the other hand, the cost of sinking the shafts has to be taken into account, the winding gear, staging, and pumping incidental to each shaft; another point to be borne in mind is that the supply of material, say bricks, must be forthcoming at the rate required by a large number of shafts.

The above represent some of the considerations to be taken into account, and it is impossible to lay down any rule or to do more than generalize.

As a rule, it is an advantage to complete a tunnel as quickly as possible, and I will give a few recent examples of rates of progress.

Totley.—Total length, 6,229 yards, *i.e.*, over $3\frac{1}{2}$ miles, occupied 5 years in construction. There were 7 shafts, 3 temporary and 4 permanent, all occurring in the first $\frac{3}{4}$-mile, and averaging a distance of 10 chains apart, the deepest shaft being 280 feet. On the remaining length of $2\frac{3}{4}$ miles there was no shaft.

The ventilation depended solely on the air supplied by the compressors working the air drills.

The strata consisted of coal measures, millstone, grit, and shale. The headings, 10 feet by 9 feet, clear of timber, were driven at a rate of 20·2 lineal yards per week of 7 days where machine drills were used, and 16·6 lineal yards without or by hand labour. The day was divided into 3 shifts of 8 hours each.

There were 51 breakups, averaging 100 yards apart. The progress of the completed work from start to finish averaged $3\frac{1}{2}$ yards per day, but throughout one year it averaged 7 yards per day, or 200 yards per month.

A breakup, I should explain, is obtained by opening up the bottom heading at convenient points to the full area of the tunnel. The diagram of Sodbury tunnel shows 13 breakups.

Cowburn Tunnel.—Total length, 3,702 yards, *i.e.*, $2\frac{1}{8}$ miles, occupied $4\frac{1}{2}$ years in construction. One shaft only was sunk, 335 lineal yards from the Edale end, and consequently there was a length of 3,367 yards (nearly 2 miles in length) without a shaft. The strata consisted of shale and rock. Headings 10 feet by 9 feet were driven at the rate of 17 lineal yards per week per face. Breakups were formed at an average distance of 85 yards. The ventilation was assisted during construction by a 16-foot diameter by 4-foot fan.

Bolsover.—Total length, 2,625 yards, *i.e.*, $1\frac{1}{2}$ miles, occupied three years in construction. Three shafts averaging about 525 yards apart, say, 24 chains. Headings were driven at the rate of 9 lineal yards per week. The strata consisted of coal measures and blue shale.

Catesby.—Total length, $1\frac{3}{4}$ miles. Ten shafts averaging 12 chain apart, the greatest distance, which was due to difficulties with the landowner, being about 30 chains. The depth of the shafts ranged from 120 to 150 feet. The tunnel took two years to complete.

You will notice from the above instances that the distance apart of the shafts varies greatly, the longest length without a shaft being 4,900 yards approximately, or about $2\frac{3}{4}$ miles in the case of Totley, whereas in the case of the same tunnel, and also of Catesby, there are several shafts where circumstances allowed only 10 or 12 chains apart.

With such a short distance as the latter the excavation can be removed by skips placed on trolleys pushed by the men, and, consequently, smaller shafts and less lifting power are required than if wagons drawn by ponies are used, such as are generally employed if the distance much exceeds that mentioned.

Further, when the shafts are as close as described, time and ventilation will probably permit of a continuous heading being dispensed with, and of length after length of brickwork being built forward from each shaft until the two portions met, a system which has been carried out on the shorter of the two tunnels on this work as previously described.

This method is more economical than if headings are first driven, as though, of course, the total quantity of excavation to be removed is the same in both cases, the cost of driving the heading is relatively more expensive per cubic yard than the cost of removing the whole excavation in one block. In other words, the cost of first driving a heading, and at a later date removing the remaining excavation, is more expensive than if the whole excavation be removed at one time. Considerations of ventilation, water, and time may, however, necessitate a heading, and where the shafts are far apart are practically certain to do so.

Taking these three points (1), it is unnecessary to state that when once the headings from two shafts join, the ventilation greatly improves, and the remaining work is carried out under much greater advantage in this respect.

2. Equally by a continuous heading water may escape entirely by gravitation, or may at any rate reach a convenient point as immediately under some shaft, where it can be more economically pumped to the surface.

3. On the question of time I will refer to the diagram of the Sodbury tunnel (*Fig.* 11).

The upper and lower lines denote respectively the top and bottom of the tunnel, and the hatched portion represents the present position of a bottom heading driven at formation level.

At certain points, as indicated, breakups occur, numbered 1, 2, 3, etc., up to 13. These are obtained by opening up the heading at the points shown to the full area of the tunnel, and at once building in a length of permanent brickwork.

When this is done it is evident that two extra faces of brickwork are obtained, from which the tunnel can be proceeded with in both directions simultaneously with any number of other faces, either from the shafts or other breakups, limited, however, by the possible delivery of material down the shaft and the removal of excavation up it.

This limit might for general purposes be put down as 6 faces of brickwork. Where, however, material can be delivered, and excavation removed from the open end of a tunnel, the number of breakups may be greatly increased.

I will now say a few words on the question of the adoption of top as against bottom headings, and incidentally it should be mentioned that a short length of top heading, perhaps 20 feet, must always be kept driven in front of the advancing brickwork, as will be explained shortly, for the purpose of getting rid of the top bars or timbers. This is essential, whether a top or bottom heading be adopted. But at present I am speaking of a continuous top heading as against a bottom.

The bottom heading is known as the English system, and the top as the Belgian or French, but it would hardly be correct to assume that the distinction always applies, as between work carried out in this country and work carried out on the Continent; there are advantages and disadvantages, and circumstances determine which is the better course to adopt.

The chief points in favour of a bottom heading are that it permits of drainage at formation level, and of the construction of breakups at convenient points, thus greatly expediting the work of construction.

A top heading can, however, sometimes be advantageously employed in hard rock, especially when there is little water, and its advantage under favourable circumstances is this—that the excavation can be removed by a series of galleries or benchings immediately behind the top heading, and in this manner the whole area of the tunnel opened out almost as rapidly as the heading can be driven. Thus fair speed can be attained, and the work carried out as already explained more economically than if a bottom heading were first driven.

This method of working in galleries would be impracticable in soft ground owing to the quantity of timbering required, and the great weight that would be brought upon it. In the case of a top heading, breakups, or in such a case perhaps I ought to say breakdowns, are evidently impossible ; for in the first place the excavation would have to be raised to the level of the top heading, and afterwards lowered to the completed length of tunnel before reaching the shaft or open end, and the same would apply to the materials brought into the tunnel for construction, such as bricks, mortar, etc.

As a matter of fact, in nearly all railway tunnels in this country bottom headings have been employed, the system of breakups probably being the determining factor as greatly expediting the time of construction.

They were employed at Totley, Cowburn, Bolsover, and are being used at Sodbury.

In the case of the Severn Tunnel a bottom heading was first driven, but in order to obtain increased security against a possible influx of water from the deep channel of the estuary above, the tunnel was lowered near the centre 15 feet, and this converted the bottom headings into top ones, and, consequently, for a length of one mile the semicircular arch of the tunnel was first built, and the invert and walls at a later date after the excavation had been completed.

Bottom headings were driven along the remainder of the tunnel, and the work expedited by means of breakups.

The Monte Cenis Tunnel was driven with a bottom heading, but no attempt was made to form breakups, the reason for this no doubt being that in a tunnel of this length, with access only from the open ends, the quantity of excavation and the supply of building material that could be passed through the tunnel was necessarily limited, and breakups, therefore, in such a case useless.

The St. Gothard Tunnel was driven with a top heading, and that this is the better course in tunnels of this length through hard rock is demonstrated by the result.

The Monte Cenis Tunnel is $7\frac{1}{2}$ miles in length, and took 13 years to complete, and cost £224 per yard forward.

The St. Gothard Tunnel is $9\frac{1}{4}$ miles in length, and took $7\frac{1}{2}$ years to complete, and cost £142 per yard forward.

The much greater progress and economy, however, of the St. Gothard Tunnel would not be due entirely to the adoption of a top heading, but also to the use of greatly improved rock drills, dynamite instead of compressed powder, to the employment of locomotives worked by compressed air, and other causes.

In both the case of the St. Gothard and Monte Cenis Tunnels the arch was built first, and the walls by a system of underpinning, when the lower and side excavation had been removed.

The Simplon Tunnel is being constructed on an entirely different system.

There are to be two separate single-line tunnels parallel to one another 56 feet apart, only one of which is to be constructed in the first place, and the second at such time as the traffic will justify.

The heading for the second tunnel is, however, being driven simultaneously with the first, and connected with it by cross-passages every 200 yards, and will assist for ventilation purposes and the removal of excavation, etc.

The headings are driven at formation level, and in the case of tunnel No. 1 shafts are raised from time to time to the roof, and headings driven in both directions.

Evidently the system is quite different from the St. Gothard and Monte Cenis, and is expected to be much more economical. The opportunity, however, of providing for a second parallel tunnel in the future is exceptional, and no comparison, therefore, can be made with the usual methods.

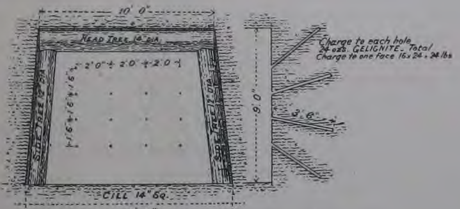


Fig. 12.

Fig. 12 shows the usual position and number of holes in driving by a machine drill a heading 10 feet by 9 feet in rock. The machine is fixed about 3 feet from the working face, and slides and pivots on a horizontal metal column, which is kept in position by jack screws at each end, by means of which the column is pressed hard against the sides of the heading.

The timbers, however, it should be mentioned, represent sizes employed where the ground is heavy, and in rock a lighter section is sufficient.

The charge consists of about 24 ounces of gelignite to each hole; the fuzes are lit simultaneously, but vary in length, those for the bottom row being the shortest and for the top the longest. The effect of this is that the charge first takes effect in the lowest row, and causes a cavity, thereby assisting the successive charges above.

Plate IV. shows the timbering for the full area of the tunnel in moderately heavy ground. You will note it consists of a top cill, a middle cill, and there is also a bottom cill on the level of the formation, which, however, the plate does not show.

Above the top cill the top heading, 6 feet by 6 feet, is just discernible; it extends only about 20 feet or so, and, as I have before mentioned, must always be kept that distance in front of an excavated length, in order to permit of the crown bars being drawn forward after the brickwork has been built.

In this case there are 14 bars, 8 of which are termed taking-out bars, and 6 drawing-bars. The taking-out bars are merely the length of the excavated section of tunnel, in this case 15 feet plus about two feet or so, to allow of the near ends resting on the completed brickwork, and the far ends on cill props clear of the site that will be occupied by the next length of brickwork to be built; and this being the case each bar can be simply removed as soon as the brickwork, which is commenced from the bottom upwards, reaches it.

In the case of the 6 drawing bars, as they are termed, it would not be safe in heavy ground to remove them before the brickwork had been built; consequently, they have not only to be put in at a height clear of the full thickness of the arch, but must also be of such a length as will permit of their extreme ends being supported clear of the excavated length of tunnel.

This is made clear by *Fig.* 13 and an explanation of the usual tunnel operations. On the left is shown a complete length of brickwork with the ribs, or centering, still in. It will be readily understood that when the brickwork just referred to was finished, the ground in front of it would not have been excavated, other than the top heading of 20 feet, and in this case the continuous bottom heading.

The first operation is, then, to draw forward the top bars until 18 inches or so rest on the completed arch and the extreme end on inclined props in the top heading. The ground in the heading is then widened out laterally, following the curve of the tunnel, and downwards, in the manner shown, until the top cill can be put in, and this permits of the vertical cill props being inserted.

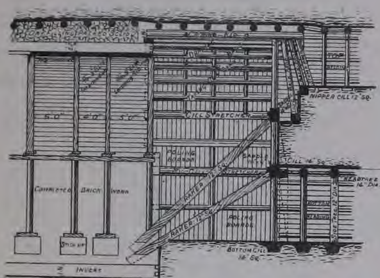


Fig. 13.

The next operation is to get in the middle cill, and to this end a special lining bar must be placed in position in the bottom heading and supported by special props, as shown by dotted lines. Next, the ground between the top and middle cill, for a width of 2 feet or so, is removed in a slanting direction, so as to enable a raking prop to be put in supporting the top cill and resting on the special lining bar already referred to. This operation is repeated until a series of raking props, with poling boards between them, have been fixed sufficient to support the top cill. The middle cill can then be got in, and the vertical props between the middle and top cills fixed. By a similar operation to that just described the ground below the middle cill is removed, the bottom cill laid in, and vertical props fixed between the bottom and middle cills.

The large raking struts, or cill-rakers, as they are termed, shown in the diagram, are evidently for the purpose of preventing the top and middle cills being thrust forward into the tunnel by the horizontal push of the ground behind them.

I pointed out that the drawing bars must be placed at a height clear of the full thickness of the arch, but, in addition, an allowance must be made for settlement due to the weight of ground; this may be anything between 6 inches and 3 feet in very heavy ground.

It is unnecessary to add that the cavities left by the crown bars must be solidly filled in with dry brick or stone tight to the ground.

In good ground drawing bars are not necessary, and in such a case the top bars are treated as the bars below, and removed before the brickwork reaches them.

With the limited time at my disposal it has not been possible to enter into great detail or to touch on the questions of ballast, permanent way, station yards, etc., and I have endeavoured, therefore, to confine my remarks more particularly to the constructive operations.

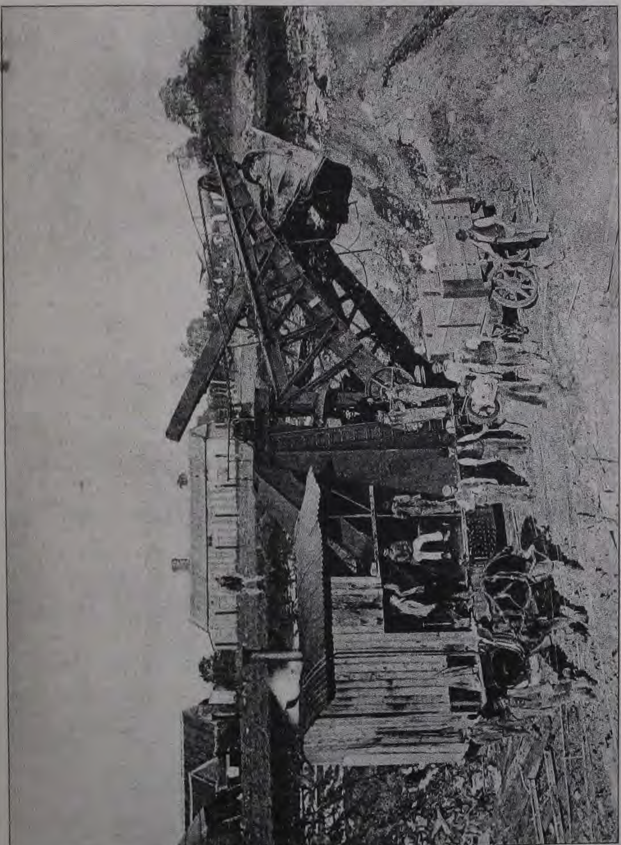
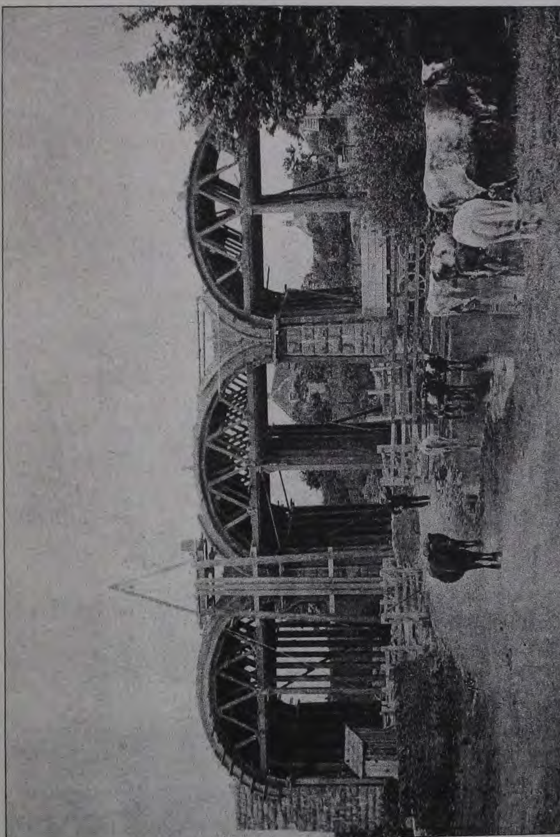
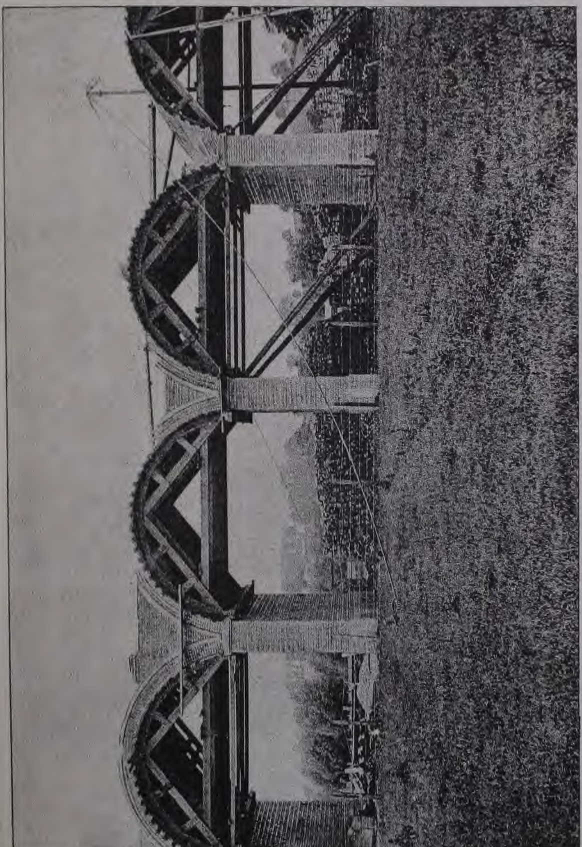
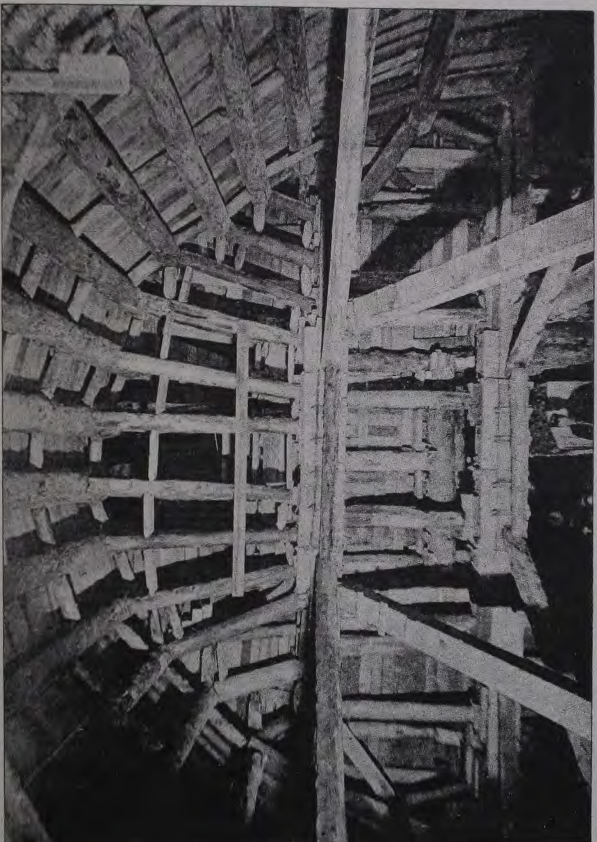


PLATE II.





RAILWAY CONSTRUCTION. PLATE IV.



LISTS OF

SERVICE ORDNANCE,

WITH DETAILS OF

GUNS, AMMUNITION, CARRIAGES, AND SLIDES.

1.—Breech-Loading Ordnance (B.L. & R.B.L.).
2.—Muzzle-Loading Ordnance (R.M.L.).
3.—Quick-Firing and Machine Guns.

Corrected to June, 1900.

WAR OFFICE.

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1.—BREECH-LOADING

BREECH-LOADING

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Ins.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Ins.	Capacity in Cubic Inches.
16·25-inch	—	Steel	111 tons	N	524·0	487·5	30·0	21·125	84·5	28660
13·5 " ...	I II, IIA, III IIIA, B, C, D, E, F† IV.	" ... ... " ... . " ... . "	69 " 67	N	433·0	405·0	30·0	18·0	66·5	17100
12 " ...	I, IA	Steel	47 "	L	328·5	301·75	25·14	14·75	55·8	9666
	III, IV, V VW	" ... ... "	45 " 46 "	N	328·5	303·0	25·25	16·0	48·0	9666

† One gun only, 13·5-inch, Mark III* is for Land Service. It is a Mark IIIF gun, with a trunnion band fitted to it.

ORDNANCE (B.L. AND R.B.L.).

ORDNANCE (B.L.).

RIFLING.								BALLISTIC EFFECTS.			ORDNANCE.	
System. / Polygroove.	Mark.	Twist.	Length in Inches	Obturation.	No. of Grooves.	Venting.		Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yards in Inches.	Nature.	Mark.
Elswick section	I	From 1 turn in 130 calibres at breech to 1 in 30 at 77·2 inches from muzzle; remainder uniform 1 in 30	397·2									Nos. 1, 2, 3.
,,	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle		Pad	78	Axial		2087	54377	32·0	16·25-inch.	Nos. 4, 5, 8, 9, 10, 11, 12
Modified plain section	*III	Straight from breech end of rifling to 299·4 inches from the muzzle, the remaining 299·4 inches increasing from 0 to 1 turn in 30 calibres at muzzle	396·9									
Hook section	I	From 1 turn in 120 calibres at breech to 1 in 30 at 166·7 ins. from muzzle; remainder uniform 1 in 30										
,,	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle										I
Plain section	III	Straight from breech end of rifling to 252·4 inches from the muzzle; the remaining 252·4 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	333·4	,,	54	,,		2016	35217	23·2	13·5 ,,	II, IIA, III IIIA, B, C, D, E, F IV
Modified plain section	*IV											
Hook section	I	From 1 turn in 104·5 calibres at breech to 1 in 35 at 124·525 ins. from muzzle; remainder uniform 1 in 35	241·45									I, IA
,,	I	From 1 turn in 120 calibres at breech to 1 in 35 at 126·275 ins. from muzzle; remainder uniform 1 in 35	260·8	,,	48	,,		1914	18137	20·4	12 ,,	III, IV, V Vw

* For guns of future manufacture and for existing guns when repaired with new A tubes or through lined.

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Ins.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Inches.	Capacity in Cubic Inches.
12-inch	VI, VII	Steel	46 tons	L	328·5	303·0	25·25	16·0	48·0	9666
12-inch, wire	VIII,	Steel (wire construction)	46 ,,	N	445·5‡	425·15‡	35·43	largest 16·0 smal'st 12·8	70·0	--
	IX	,, ,, ,, ...	50 ,,	N	496·5	480·0	40·0	largest 17·5 smal'st 12·75	87·2	—
10-inch ...	I	Steel	32 ,,	L	342·4	320·0	32·0	14·0	54·0	8370
	II, III, IIIA, IV	,, ...	29 ,,	C						
9·2 ,,	IA c.I, u.c.I	Wrought iron and steel	22 ,,	N L	255·8	235·23	25·56	11·0	44·0	4300
	IIA	,, ,, ,, ,,	21 ,,	N						
	III V	Steel	24 ,, 22 ,,	N	310·0	289·8	31·5	12·0	43·0	4950
	IV, c.IVA, u.c.IVA		23 ,,	L						
	VI, VIA, VIc VIB VII		22 ,,	C L N						

‡ 12 inch wire, Mark VIII, guns of future manufacture will be ·1 of an inch longer than these dimensions.

Rifling.							Ballistic Effects.			Ordnance.	
System. / Polygroove.	Mark.	Twist.	Length in Inches.	Obturation.	No. of Grooves.	Venting.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yards in Inches.	Nature.	Mark.
Hook section	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle	250·8	Pad	48	Axial	1914	18137	20·4	12-inch	VI, VII
Modified plain section	I	Straight from breech end of rifling to 278·95 ins. from the muzzle, the remaining 278·95 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	349·285 349·385‡	,,	48	,,	2367	—	28·6	12-inch, wire	VIII
—	—	— — —	—	—	—	—	—	—	—		IX
Hook section	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle	259·68‖	Pad	40	Axial	2040	14391	20·5	10-inch	I II, III, IIIA IV
Modified plain section	*III	Straight from breech end of rifling to 202·18 ins. from the muzzle, the remaining 202·18 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	262·18								
Hook section	I	From 1 turn in 118·5 calibres at breech to 1 in 35 at 18·12 ins. from muzzle, remainder uniform 1 in 35	187·73	,,	37	,,	1781	8406	15·9	9·2-inch	IA, C.I, U.C.I. IIA
,,	I	From 1 turn in 120 calibres at breech to 1 in 30 at 120·4 ins. from muzzle; remainder uniform 1 in 30	243·4				2065	10915	18·8		III V IV, cIVA, U.C.IVA VI, VIA, VIC VIB VII
,,	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle									
Modified plain section	*III	Straight from breech end of rifling to 188·2 ins. from the muzzle, the remaining 188·2 ins. increasing from 0 to 1 turn in 30 calibres at muzzle									

* For guns of future manufacture and for existing guns when repaired with new A tubes or through lined.
‡ 2·5 inches at the muzzle of Mark I guns are unrifled.

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight	Service.	Total Length in Ins.	Length in Ins.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Inches.	Capacity in Cubic Inches.
9·2-inch ...	VIII	Steel (wire construction)	25 tons	N	384·0	368·75	40·08	largest 10·5 smallest 9·8	35·15	–
	IX		27 ,,	L	445·25	430·0	46·74	largest 13·0 smallest 9·8	71·215	—
	X		28 ,,	C	442·35	429·33	46·66	largest 13·0 smallest 10·2	71·0	—
8 ,, ...	III	Steel, chase-hooped	14 ,,	N	222·5	201·1	25·1	10·5	34·5	3050
	IV	,, ,,	15 ,,	N	254·5	236·9	29·61	10·5	38·0	3350
	VI	Steel	14 ,,							
	VII	Wrought iron and steel	12 ,,	L	218·5	204·0	25·5	10·5	38·0	3240

ORDNANCE (B.L.).—Continued.

Rifling.						Venting.	Ballistic Effects.			Ordnance.	
System. / Polygroove.	Mark.	Twist.	Length in Inches.	Obturation.	No. of Grooves.		Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yards in Inches.	Nature.	Mark.
Modified plain section	I	Straight from breech end of rifling to 247·14 ins. from the muzzle, the remaining 247·14 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	310·985	Pad	37	Axial	2347	—	21·3	9·2-inch	VI
"	I	Straight from breech end of rifling to 303·585 ins. from the muzzle, the remaining 303·585 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	354·685	Pad	37	Axial	2601	17826	27·5	9·2-inch	IX
"	I	Straight from breech end of rifling to 303·585 ins. from the muzzle, the remaining 303·585 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	353·8	Pad	37	Axial	—	—	—	9·2-inch	X
Hook section	I	From 1 turn in 120 calibres at breech to 1 in 35 at 63·9 ins. from the muzzle; remainder uniform 1 in 35	167·4	"	32	"	1953	5552	13·4	8-inch	III
"	I	From 1 turn in 110 calibres at breech to 1 in 35 at 99·7 ins. from the muzzle; remainder uniform 1 in 35	195·8	"	32	"	2150	6729	14·9	8-inch	IV
"	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle	195·8	"	32	"	2200	7046	15·2	8-inch	VI
Modified plain section	*III	Straight from breech end of rifling to 147·8 ins. from the muzzle, the remaining 147·8 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	195·8	"	32	"	2200	7046	15·2	8-inch	VI
Elswick section	I	From 1 turn to 100 calibres at breech to 1 in 40 at 6·82 ins. from the muzzle; remainder uniform 1 in 40	162·82	Cup	33	"	2000	4992	12 8	"	VII

* For guns of future manufacture and for existing guns when repaired with new A tubes or through lined.

Ordnance.						Bore.		Chambers.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Inches.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Inches.	Capacity in Cubic Inches.
8-inch	VIIA	Steel	13 tons	L	222·5	208·0	26·0	10·5	38·5	3292
80-pr.	I	Wrought iron & steel, chase-hooped	82 cwt.	N	162·6	153·2	25·53	7·5	28·05	1185
6-inch ...	III	Steel, chase-hooped	5 tons	N	170·7	153·2	25·53	8·0	26·75	1364
	IV, VI VIA	Steel ... ... ,, ...	5 ,, 5 ,,	C L	173·5	156·0	26·0	8·0	26·75	1364
	V	,, ...	5 ,,	L	195·3	183·5	30·58	8·0	31·75	1515
	VII	Steel (wire construction)	7 ,,	C	279·228	269·5	44·9	largest 8·5 smal'st 6·715	32·3	1715

Rifling.						Venting.	Ballistic Effects.			Ordnance.	
System. Polygroove.	Mark.	Twist.	Length in Inches.	Obturation.	Number of Grooves.		Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yards in Inches.	Nature.	Mark.
Elswick section	I	From 1 turn in 100 calibres at breech to 1 in 40 at 10·82 ins. from the muzzle; remainder uniform 1 in 40	166·82	Cup	33	Axial	2000	4992	12·8	8-inch	VIIA
,,	I	From 0 at breech to 1 turn in 40 calibres at 4·02 ins. from the muzzle; remainder uniform 1 in 40	123·02	,,	28	,,	1800	1960	8·5	80-pr.	I
Hook section	I	From 1 turn in 120 calibres at breech to 1 in 35 at 58·9 ins. from the muzzle; remainder uniform 1 in 35	124·075		24	,,	§1672	1938	8·8		III
,,	I	From 1 turn in 120 calibres at breech to 1 in 35 at 61·75 ins. from the muzzle; remainder uniform 1 in 35		Pad			1960	2663	10·5		
			126·875		24	,,	¶1870	2425	9·8		IV, VI, VIA
,,	II	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle									
Elswick section	I	From 0 at breech to 1 turn in 30 calibres at muzzle								6-inch	
Modified plain section	*II	Straight from breech end of rifling to 113·75 ins. from the muzzle, the remaining 113·75 ins. increasing from 0 to 1 turn in 30 calibres at muzzle	149·75	Cup	28	,,	1920	2585	10·2		V
,,	I N.	Straight from breech end of rifling to 211·06 ins. from the muzzle, then increasing from 0 to 1 turn in 30 calibres at muzzle	234·783	Pad	24	,,	2493	4335	15·20		VII

* For guns of future manufacture and for existing guns when repaired with new A tubes or through lined.

§ Except with Mark III chasehooped guns on V.B. and V.C.P. carriages, when ballistics are the same as for Marks IV and VI guns.

¶ With charges of prism[1] black and P[2]

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Inches.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Inches	Capacity in Cubic Inches.
6-inch ...	VIII	Steel (wire construction)	7 tons	N	279·228	269·5	44·9	largest 8·5 small'st 6·715	32·3	1715
	IX X	Steel ... ... ,, ...	7t'ns6ct.	—	300·0	—	—	—	—	—
	XI	—	—	—	—	—	—	—	—	—
5-inch ...	IP	Steel	36 cwt.	N	139·5	125·35	25·07	5·75	19·3	510
	II	,, unchase-hooped	38 ,,	N	139·5	125·35	25·07	5·75	19·05	504
	II	,, chase-hooped	38 ,,	C	137·0	122·85	24·57	5·75	19·05	504
	III, IV, V	,, ...	40 ,,	C	139·15	125·0	25·0	5·75	19·05	504
4-inch ...	III IIIA, IV V, VI	Steel ... ... ,, ... ,, ...	23 ,, 26 ,, 26 ,,	N N C	120·0	108·0	27·0	5·3	18·5	417
4-inch (jointed)	I	Steel	25 ,,	Indian	110·8	101·8	25·45	—	—	—

Rifling.							Ballistic Effects.			Ordnance.	
System. / Polygroove.	Mark.	Twist.	Length in Inches.	Obturation.	No. of Grooves.	Venting.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yards in Inches.	Nature.	Mark.
Modified plain section	II L.	Straight from breech end of rifling to 198·8 ins. from the muzzle, then increasing from 0 to 1 turn in 30 calibres at muzzle	234·783	Pad	24	Axial	2493	4335	15·20	6-inch	VIII
—	—	— — —	—	,,	—	,,	2610	4723	—	,,	IX X
—	—	— — —	—	,,	—	—	—	—	—	,,	XI
Hook section	I	From 1 turn in 117 calibres at breech to 1 in 30 at 51·9 ins. from breech; remainder uniform 1 in 30	104·33								IP
	I	From 1 turn in 120 calibres at breech to 1 in 25 at 52·15 ins. from the muzzle; remainder uniform 1 in 25	104·33								II
,,	I	From 1 turn in 120 calibres at breech to 1 in 25 at 49·65 ins. from the muzzle; remainder uniform 1 in 25	101·8	,,	20	Axial	1750	1062	6·25	5-inch	
,,	I	From 1 turn in 120 calibres at breech to 1 in 25 at 51·8 ins. from the muzzle; remainder uniform 1 in 25	103·95								III, IV, V
,,	I	From 1 turn in 120 calibres at breech to 1 in 30 at 43·77 ins. from the muzzle; remainder uniform 1 in 30	87·77	,,	16	,,	1900	626	5·4	4-inch	III
,,	II	From 1 turn in 120 calibres at breech to 1 in 30 at 43·77 ins. from the muzzle; remainder uniform 1 in 30			24						IIIA, IV V, VI
,,	I	From 1 turn in 120 calibres at breech to 1 in 30 at muzzle	82·0	,,	20	Radial steel	—	—	—	4-inch (jointed)	I

Ordnance.						Bore.		Chambers.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Inches.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile in Inches.	Capacity in Cubic Inches.
30-pr. (4-in. calibre)	I	Steel	20 cwt.	Indian	115·0	108·0	27·0	4·2	17·5	250
15 pr. (3-in. calibre)	I IV	,, ...	7 ,,	L	92·35 89·05	84·0	28·0	3·625 3·6	11·0	117 —
12-pr. cwt. (3-in. calibre)	I IV	Steel (wire construction) ...	6 ,,	L	66·75 71·05	59·0 66·0	19·66 22·0	3·2 3·35	8·35 7·5	70 —
32-pr. S.B.B.L. (6·35-in. calibre)	I	Cast Iron	42 ,,	L	97·6	86·0	13·5	6·55	4·1	136
HOWITZERS. 8-inch 70 cwt.	I	Steel	70 ,,	L	116·0	104·0	13·0	8·4	8·8	—
6-inch 30 cwt	I	,, ...	30 ,,	L	94·0	84·0	14·0	6·4	6·7	229
6-inch 25 cwt	I	,, ...	25 ,,	Indian	82·0	72·0	12·0	6·4	10·2	341
5·4-inch ..	I	,, ...	13 ,,	,,	62·0	54·0	10·0	5·6	3·4	96
5-inch	I	,, ...	9 ,,	L	49·0	42·0	8·4	5·2	3·2	77

Rifling.							Ballistic Effects.			Ordnance.	
System. / Polygroove.	Mark.	Twist.	Length in Inches.	Obturation.	No. of Grooves.	Venting.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Seconds.	Penetration of Wrought Iron at 1,00 Yards in Inches.	Nature.	Mark
Hook section	I	From 1 turn in 120 calibres at breech to 1 in 30 at 44·8 ins. from the muzzle; remainder uniform 1 in 30	88·3	Pad	24	Axial	1621	—	—	30-pr.	
,,	I	From 1 turn in 120 calibres at breech to 1 in 28 at 35·8 ins. from the muzzle; remainder uniform 1 in 28	71·6	,,	12	Radial T.	**1574	—	—	15-pr.	I
,,	II	From 1 turn in 120 calibres at breech to 1 in 28 at 35·8 ins. from the muzzle: remainder uniform 1 in 28	71·6	,,	18	,,	1581	—	—	15-pr.	IV
,,	I	From 1 turn in 105 calibres at breech to 1 in 28 at 15 ins. from the muzzle; remainder uniform 1 in 28	49·25	,,	18	Axial T.	1553	—	—	12-pr. 6 cwt.	I
,,	I	From 1 turn in 120 calibres at breech to 1 turn in 28 calibres at muzzle.	57·1	,,	18	,,	—	—	—	12-pr. 6 cwt.	IV
—	—	Smooth bore	—	Cup	—	Radial copper	—	—	—	32-pr. S.B.B.L.	I
Hook section	I	Uniform, 1 turn in 15 calibres	92·1	Pad	32	Axial T.	--	—	—	8-inch 70-cwt.	I
,,	I	Uniform, 1 turn in 15 calibres	74·9	,,	24	,,	777	—	—	6-inch 30-cwt.	I
,,	I	Uniform, 1 turn in 15 calibres	59·425	,,	24	Axial	779	—	—	6-inch 25-cwt.	I
,,	I	Uniform, 1 turn in 28 calibres	48·4	,,	21	Axial T.	781	—	—	5·4-inch	I
,,	I	Uniform, 1 turn in 28 calibres	36·8	,,	20	,,	782	—	—	5-inch	I

** On Mark II carriage the muzzle velocity is 1,569 ft. secs.

-LOADING O

Ordnance, B.L.		Common.			Commo		Tubes.	ORDNANCE, B.L.		
5-in. ..	II to V	Vo	42 4	7 12	I, IIp	50	Percussion ..		...	II, III, IV, V
		IVo	41 8	8 0						
		III, VIq	46 $4\frac{3}{4}$	3 5						
4-in. ...	IIP, III to VI	III, VIIIq	22 14	1 12	I, IIp Iqw	25	,,		...	IIP, III, IIIA, IV, V, VI
4-in. jointed	I	V, VIo	21 7	3 3	Iqn			nted	...	I
30-pr. ..	I	Ip	26 $9\frac{3}{4}$	3 0	—	30	T. friction		...	I
15-pr. ...	I	—	—	—	—	$12\frac{8}{16}$ $12\frac{14}{16}$ $12\frac{4}{16}$	,, Solid drawn Special I		...	I
12-pr. 6 cwt.	I	—	—	—	—	$12\frac{8}{16}$ $12\frac{14}{16}$ $12\frac{4}{16}$	T. friction	wt.	...	I
32-pr., S.B.B.L	I	—	—	—	—	$54\frac{1}{2}$	Short or solid drawn	pr. B.L.		I
Howitzers.								ZERS.		
8-in. 70 cwt.	I	—	—	—	—	—	T. friction ..	wt.	...	I
6-in. 30 cwt.	I	Ip	103 8	14 7	—	100	T. friction.	wt.	...	I
		IIn	113 5	9 4			V.S.T. double wired			
6-in. 25-cwt.	I	Iq	107 9	10 11			V.S. Percussion I			
		I, IIq	112 12	9 4			V.S. Electric P. VII	wt.	...	I
5·4-in. ...	I	I, IIq	55 0	4 7	—	60	T. friction		...	I
		I, IIp	53 $10\frac{1}{2}$	5 $12\frac{1}{4}$						
5-in. ...	I	I, IIq	46 4	3 3	—	50	,,		...	I

a In 8 cartridges.
b ,, 6 ,,
c ,, 4 ,,
d ,, 3 ,,
e ,, 2 ,,
f For Mark III chase hooped, and Marks

ge for Mark III chase
, and Mark IV guns
s on A.B. mountings. rk III on sea
and V guns.
nly.

Nature.	Mark.	Materials.	Service.	Total Length.	Bore.		Chamber.			Rifling.			Vent.	Ballistic Effects with Full Charges.			
					Calibre.	Length in Calibres.	Diameter.	Length to base of Projectile.	Capacity.	System.	Twist in Calibres.	Length.	Position.	Muzzle Velocity.	Muzzle Energy.	Penetration of Wrought-Iron Armour Plate. At 1,000 Yards.	Penetration of Wrought-Iron Armour Plate. At 2,000 Yards.
				Ins.	Ins.		Ins.	Ins.	Cubic Ins.			Ins.		F.s.	Ft.-tons	Ins.	Ins.
7-in. 82 cwt. ...	—	Wrought-iron	L	120·0	7·0	14·21	7·20	16·0	620·0	Polygroove	U. 1 in 37 cals ...	83·1	*a* Through vent-piece, striking cartridge at centre of base.	1100*b*	847	5	[illegible]
7 ,, 72 ,, ...	—	,, ,,	L	118·0	7·0	14·21 or 13·93	7·20	14·25	552·9	,,	,, 1 in 37 ,, ...	82·9		1100*b*	847	5	[illegible]
40-pr. 35 cwt. ...	—	,, ,,	C	121·0													
40-pr. side closing	—	,, ,,	L		4·75	22·39	4·96	13·5	257·8	,,	,, 1 in 36½ ,, ...	92·5		1160	374	—	—
40-pr. 32 cwt. ...	—	,, ,,	L	120·0													
20 ,, 16 ,, ...	—	,, ,,	L	96·0	3·75	22·86	3·94	12·0	143·0	,,	,, 1 in 38 ,, ...	71·6		1130	124	—	—
20 ,, 15 ,, ... 20 ,, 13 ,, ...	—	,, ,,	N	66·125	3·75	14·48	3·94	11·0	131·0	,,	,, 1 in 38 ,, ...	42·75		1000	156	—	—
12 ,, 8 ,, ...	—	,, ,,	C	72·0	3·0	20·458	3·20	8·5	66·0	,,	,, 1 in 38 ,, ...	52·5		1239	119	—	—
9 ,, 6 ,, ...	—	,, ,,	L	62·0	3·0	17·5	3·20	7·0	55·1	,,	,, 1 in 38 ,, ...	45·5		1055	66	—	—

a 40-pr. side-closing has a copper radial vent 6·5 inches from end of bore inclined at an angle of 45° to vertical plane of axis of gun on right side.
b Difference in size of chamber gives the same M.V. in these two guns, although fired with different charges.

ORDNANCE. — Nature and Weight.	Mark.	FUZES. Time. L.S.	FUZES. Time. S.S.	FUZES. Percussion. L.S.	FUZES. Percussion. S.S.	TUBES.	CHARGES. Silk Cloth Cartridge. Full.	CHARGES. Silk Cloth Cartridge. Saluting Blank, R.L.G. or L.G.
							lb.	lb. oz.
7-in. 82 cwt. ...	—	15 secs. with det. III. Mid. sensitive. T. & P., mid. No. 54*b*	15 secs. with det. III, mid. sensitive*b*	Direct Action	—	Short or solid drawn with prim	11 R.L.G.2*c*	7 0
,, 72 ,, ...	—	,,	,,	,,	—	,,	10 ,, *c*	7 0
40-pr. 35 ,, / ,, side closing. / ,, 32 cwt.	—	,,	15 secs. with det. III, mid. sensitive*b*	R.L., No. 3, Small, No. 8, III* and IV*b*	R.L. perc. and Dir. Act.	Solid drawn with ball, *d* solid drawn without ball, and short*e*	5 R.L.G.2	3 0
20-pr. 16 ,, ..	—	E. time	—	B.L. plain	—	Short or solid drawn, without ball	2½ ,,	1 8
,, 15 ,, / ,, 13 ,,	—	—	E. time	,,	R.L. and Dir. Act for Com. B.L. plain for segment	,,	2¼ ,,	1 8
12-pr. 8 ,, ..	—	15 secs. with det. III*b*, E. time for segment	,,	,,	B.L. plain	,,	1½ ,,	1 0
9-pr. 6 ,, ...	—	,,	,,	,,	,,	,,	1⅜ ,,	1 0

b For future use.

c Owing to difference in size of chamber in the two guns, the same M.V. is obtained from both.

d For side closing guns.

e For other than side closing guns, the latter tube in conjunction with vent-piece primer

Projectiles.													Ordnance.
With Lead Coating.									Solid Shot.	Case Shot.			Nature and Weight.
Empty.					Bursting Charges.								
mmon Shell.	Segment Shell.		Shrapnel Shell.		Common Shell. P.&F.G.	Common Shell. L.G.	Segment Shell.	Shrapnel Shell.					
lb. oz.	Mk.	lb. oz.	Mk.	lb. oz.	lb. oz.	lb. oz.	lb. oz. gr.	lb. oz.	lb. oz.	Mk.	lb. oz.		
33 0 98 0	I	98 $9\frac{11}{16}$	II	97 0	8 4 10 5	6 12 8 8	3 2 0	0 8	—	VI	68 $2\frac{1}{2}$		7-in., 82 cwt.
98 0	I	98 $9\frac{11}{16}$	II	97 0	10 5	8 8	3 2 0	0 8	—	VI	68 $2\frac{1}{2}$		,, 72 ,,
38 5	I	38 $9\frac{3}{4}$	I	39 0	2 6	2 0	0 13 0	0 3	40 $13\frac{1}{2}$	II	31 8		40-pr., 35 cwt. ,, 32 ,,
20 8	II	19 10	—	—	—	1 2	700grs Shell, F.G.	—	20 $6\frac{1}{4}$	IV	20 $5\frac{1}{2}$		20-pr., 16 cwt.
20 8	I	19 10	—	—	1 5	1 2	700 ,, Shell, F.G.	—	20 $9\frac{1}{4}$	—	—		,, 15 ,, ,, 13 ,,
10 12	I	10 8	II	10 12	—	0 8	550 ,, Shell, F.G.	0 $0\frac{3}{4}$	11 7	IV	11 8		12-pr., 8 cwt.
8 3	I	8 5	II	8 12	—	0 6	300 ,, Shell, F.G.	0 $0\frac{3}{4}$	8 13	III	9 0		9-pr., 6 cwt.

ORDNANCE. — Nature and Weight.	Mark.	FUZES.				TUBES.	CHAR
		Time.		Percussion.			Silk Cartri
		L.S.	S.S.	L.S.	S.S.		Full.
							lb.
7-in. 82 cwt. ...	—	15 secs. with det. III. Mid. sensitive. T. & P., mid. No. 54*b*	15 secs. with det. III, mid. sensitive*b*	Direct Action	—	Short or solid drawn with prim	11 R.L.G
,, 72 ,, ...	—	,,	,,	,,	—	,,	10 ,,
40-pr. 35 ,, / ,, side closing. / ,, 32 cwt.	—	,,	15 secs. with det. III, mid. sensitive*b*	R.L., No. 3. Small, No. 8, III* and IV*b*	R.L. perc. and Dir. Act.	Solid drawn with ball, *d* solid drawn without ball, and shorte	5 R.L.G
20-pr. 16 ,, ..	—	E. time	—	B.L. plain	—	Short or solid drawn, without ball	2½ ,,
,, 15 ,, / ,, 13 ,,	—	—	E. time	,,	R.L. and Dir. Act for Com. B.L. plain for segment	,,	2¼ ,,
12-pr. 8 ,, ..	—	1 5 secs. with det. III*b*, E. time for segment	,,	,,	B.L. plain	,,	1½ ,,
9-pr. 6 ,, ...	—	,,	,,	,,	,,	,,	1⅛ ,,

b For future use.

c Owing to difference in size of chamber in the two guns, the same M.V. is obtained from b

d For side closing guns.

e For other than side closing guns, the latter tube in conjunction with vent-piece primer

ORDNANCE (R.B.L.).—Continued.

Projectiles. With Lead Coating. Empty. Common Shell. Mk.	Common Shell. lb. oz.	Segment Shell. Mk.	Segment Shell. lb. oz.	Shrapnel Shell. Mk.	Shrapnel Shell. lb. oz.	Bursting Charges. Common Shell. P.&F.G. lb. oz.	Bursting Charges. Common Shell. L.G. lb. oz.	Bursting Charges. Segment Shell. lb. oz. gr.	Bursting Charges. Shrapnel Shell. lb. oz.	Solid Shot. lb. oz.	Case Shot. Mk.	Case Shot. lb. oz.	Ordnance. Nature and Weight.
II —	33 0 98 0	I	98 $9\frac{11}{16}$	II	97 0	8 4 10 5	6 12 8 8	3 2 0	0 8	—	VI	68 $2\frac{1}{2}$	7-in., 82 cwt.
—	98 0	I	98 $9\frac{11}{16}$	II	97 0	10 5	8 8	3 2 0	0 8	—	VI	68 $2\frac{1}{2}$	,, 72 ,,
II	38 5	I	38 $9\frac{3}{4}$	I	39 0	2 6	2 0	0 13 0	0 3	40 $13\frac{1}{2}$	II	31 8	40-pr., 35 cwt. ,, 32 ,,
II	20 8	II	19 10	—	—	—	1 2	700grs	—	20 $6\frac{1}{4}$	IV	20 $5\frac{1}{2}$	20-pr., 16 cwt.
III	20 8	I	19 10	—	—	1 5	1 2	700 ,, Shell, F.G.	—	20 $9\frac{1}{4}$	—	—	,, 15 ,, ,, 13 ,,
III	10 12	I	10 8	II	10 12	—	0 8	550 ,,	0 $0\frac{3}{4}$	11 7	IV	11 8	12-pr., 8 cwt.
III	8 3	I	8 5	II	8 12	—	0 6	300 ,,	0 $0\frac{3}{4}$	8 13	III	9 0	9-pr., 6 cwt.

B.L. CARRIAGES AND SLIDES (LAND SERVICE).

Ordnance.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.		Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated).	Weight.	
	Material.	Nature.			Material.	Nature.	Front.	Rear.		Carriage.	Slide.
							ft. in.	ft. in.	ft. in.	ts. ct.	ts. ct.
12 in. {47 tons, 46 ,,}	Steel	Upper or lower tier.	7	4	Steel	Lower tier ...	9 2	21 2	5 1⅛	8 2¾	14 4¾
					..	Upper tier ...	9 2	18 0			13 19½
10 in. {32 ,,, 29 ,,}	..	Disappearing, Mk. I.	15	5	—	—	6 0	6 0	15 3·1	60 11	—
	..	Do. Mk. IA								—	—
	..	Do. Mk. II ...	15	5†	—	—	10 2·45	10 2·45	15 11	—	—
	..	Do. Mk. III ...	16	7	—	—	¶9 9¼ / **10 2¼	9 9¼ / 10 2¼	21 6	53 12	—
	..	Barbette, Mk. I	15	6½	Steel	Barbette, Mk. I, C. pivot.	5 11·13	5 11·13	9 2	11 4	9 13¾
					..	Do do. D pivot	9 6	8 8¾	9 2		10 11⅛
	..	Do. Mk. II ...	17	5	..	Do. Mk. II ..	10 10	10 10	9 8½	11 3	45 11
	..	Do. Mk. III ..	15	5	..	Do. Mk. III ..	10 10	10 10	9 4·8	7 3½	41 16⅞
9·2-in. {22 ,,, 23 ,,}	..	Disappearing, Mk. I	15	5	—	—	5 6	5 6	14 3·5	50 5¼	—
	..	Do. Mk. II ...	15	5	—	—	13 6	13 6	14 6	43 18	—
	..	Barbette, Mks. I, IA, and IB	15	6½	Steel	Barbette, Mks. I, IA, and IB	5 11·13	5 11·13	9 2	11 4	10 9½
	..	Do. Mk. II ..	17	5	..	Do. Mk. II ..	10 10	10 10	9 8½	11 3	45 11
	..	Do. Mk. III ...	15	10	..	—	4 4	4 4	5 6·5	19 18	—
	..	Do. Mk. IV ...	15	20	..	—	4 4	4 4	5 11·5	26 3	—
	..	Do. Mk. V ...	15	10	..	—	—	—	—	—	—
8-in. {12 ,,, 13 ,,}	Iron	Do. Mk. I ..	12½	5	Iron	Barbette, Mk. I	5 6	5 6	7 7⅝	4 11¾	3 17⅛
6-in., 5 tons	Steel	‡Disappearing, Mk. I.	15	5	—	—	5 0	5 0	10 5·25	15 5	—
	..	§Do. Mks. II & II*.	20	5	—	—	4 4	4 4	10 5·25	14 5½	—
	..	‡Do. Mk. III ..	20	5	—	—	4 4	4 4	10 5·25	14 16¼	—
	..	§Do. Mk. IV ..	20	5	—	—	4 4	4 4	10 5·25	13 3	—
	..	Barbette, Mk. I	15	7	Steel	Barbette, Mks I and I*.	3 9	3 9	4 8	2 12	2 10
	..	Do. Mk. I* ...	15	10							
	..	Do. Mk. II ...	15	10	..	—	2 6	2 6	2 10	8 10	—
	..	V.C.P. Mk. I ...	15	15	..	V.C.P., Mk. I	2 3¼	2 3¼	3 6¼	6 7	—
	..	C.P., Mk. I ...	20	10	..	—	—	—	3 7·1§§	5 16	—
	..	Do., Mk. II ...	20	10††	..	—	—	—	3 6·3§§	8 10	—
5-in., 40 cwt.	..	Travelling, 6-ft. parapet.	25	5	—	—	—	—	6 6¶¶	1 15	0 12½‡‡
	..	‖Disappearing, 8-ft. parapet.	16	10	—	—	—	—	10 0¶¶	—	—
	..	Vavasseur, Mk. I	20	7½	—	Vavasseur, Mk. I.	Circular	Base plate.	3 0	0 12	0 19⅛
	..	Do., Mk. II ...	15	7½	—	Do. Mk. II.	Base plate	6 7·875	3 1·15	0 11⅓	1 7½
	..	Do., Mk. III ...	22	7½	—	Do. Mk. III.	.. ..	6 4 5	3 1·15	0 11⅓	1 6
4-in., 26 cwt. ...	..	Travelling, 6-ft parapet.	25	5	—	—	—	—	6 6¶¶	1 9	0 12½‡‡
4-in., 25 .. ... (jointed gun)	..	‖Travelling ...	17	8	—	—	—	—	3 7½¶¶	0 18	—
30-pr., 20 cwt. ...	..	‖Field, hydraulic	—	—	—	—	—	—	—	—	—
15-pr., 7 cwt.	..	Field, Mk. I* ..	16	8	—	—	—	—	3 3½¶¶	0 12½	0 8¾‡‡
	..	Do. Mk. II* ..	16	5	—	—	—	—	3 4¶¶	0 11¾	0 8½‡‡
	..	Do. Mk. III ...	16	8	—	—	—	—	—	—	—
	..	Do. Mk. III* ...	16	8	—	—	—	—	—	—	—
12-pr., 6 cwt. ..	..	Do Mk. I ...	16	8	—	—	—	—	3 4¶¶	0 9¾	0 8¾‡‡
		Do. Mk. I* ...	16	8	—	—	—	—	3 4¶¶	—	—
32-pr., S.B., B.L., 42 cwt.	Iron	Sliding, Medium No. 6.	10	15	Iron	Traversing, Medium, No. 6	1 6	6 10	3 7	0 14¼	0 13
HOWITZERS.											
8-in., 70 cwt. ...	Steel	Siege ...	70	0	—	—	—	—	4 8¶¶	3 18¼a	—
6-in., 30	..	Do. Mk. I ...	35b	—	—	—	—	—	4 5½¶¶	1 10	0 14¾‡‡
		Do. Top ...	—	—	—	—	—	—	4 10e¶¶	0 7¾	—
6-in., 25 cwt. ...	..	Do. Mk. I ..	35b	—	—	—	—	—	4 5½¶¶	2 0	0 14¾‡‡
		Do. Top ...	—	—	—	—	—	—	4 5½e¶¶	0 7	—
5·4-in., 13 cwt.	..	Field, Mk. I ...	45	5	—	—	—	—	3 9¶¶	0 14¼	—
5-in., 9 cwt. ...	..	Do. Mk. I ..	45	5	—	—	—	—	3 7¶¶	0 14¼	0 11½

† 7½° if emplacement admits. ‡ For Mark V gun. § For Marks IV and VI guns. ‖ For India. ¶ Inner. ** Outer. †† With shield, and 20 without shield. ‡‡ Weight of limber, without stores. §§ Above top of pedestal. ¶¶ Above the ground. *e* When used as a howitzer bed.
b When used with top carriage as howitzer bed 70° can be obtained.
a Weight of wood ground platform, 57cwt. 2qrs. 0lb. Weight of steel bed plate with racer and rack, 62cwt. 2qrs. 7lb.

R.B.L. CARRIAGES AND SLIDES.

Ordnance.	Carriages. Material.	Carriages. Nature.	Elevation in Degrees.	Depression in Degrees.	Slides (Traversing, Medium). Material.	Slides (Traversing, Medium). Nature.	Radii of Racers. Front.	Radii of Racers. Rear.	Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated).	Weight. Carriage.	Weight. Slide.
							ft. in.	ft. in.	ft. in.	ts. ct.	ts. ct.
7-in., 82 cwt.	Iron	Moncrieff, with platform.	15	5	—	—	† 6 10	6 10	10 5¾	13 2¾	—
							‡ 8 11	4 8½			
	,,	Sliding, Medium, No. 1.	13½	8½	Iron	No. 1, 4ft. 3in. parapet converted	5 0	14 0	5 5½	1 11¼	2 10
					,,	No. 2, 3ft. 6in. do.	5 0	14 0	4 8½		2 10
					,,	No. 3, 2ft. 7in. do.	5 0	14 0	3 9½		2 10
	,,	Do. do., No. 2 ...	13½	8½	Wood	No. 11, 4ft. 3in. parapet.	† 6 1	6 1	5 2¾	1 3¾	2 4
							‡ 9 0	3 4¼			
							§10 8¾	2 2			
							‖12 10	2 2			
					,,	No. 12, 3ft. 6in. parapet.	5 0	16 6	4 7½	—	1 14¾
	,,	Do. do., No. 3 .	13½	8½	,,	No. 13, 3ft. 6in. parapet 11′ long	5 0	14 0	4 8½	1 11¼	1 10¾
	Wood	Do. do., No. 15...	*8	6	,,	No. 14, casemate	5 0	16 6	3 7¼	0 15	1 7
							† 6 1	6 1	—	—	—
	,,	Do. do., No. 16...	*22	6	,,	No. 16, dwarf	‡ 9 3	3 4¼	5 2½	0 15½	--
7-in., 72 cwt.	,,	Do. do., No. 17...	*19	6			§10 8¼	2 2	—	—	1 17
							‖12 10	2 2	5 2	0 15	—
	,,	Do. do., No. 18...	*8½	6	,,	No. 15, converted	—	—	3 7½	0 14½	0 18¾
40-pr., 35 and 32 cwt.	Iron	Common standing.	24	9	—	—	—	—	3 5	0 17¼	—
	,,	Siege, 6-ft. parapet, side closing	15	5	—	—	—	—	6 5½G	1 6¾	¶ 13¼
	Wood	Siege	11	8½	—	—	—	—	4 4G	1 8	¶ 12
	Iron	Sliding, Medium, No. 4.	8	15	Iron	No. 4	1 7½	8 7½	3 9¾	1 1	1 2
	Wood	Do. do., No. 19...	*17½	6	Wood	No. 14, casemate	5 0	16 6	3 8½	0 10½	1 7
	,,	Do. do., No. 20...	*20	5	,,	No. 17, dwarf ...	5 0	16 6	4 10½	0 11½	1 12¾
20-pr., 16 cwt.	Iron	Do. do., No. 5	10	15	Iron	No. 5	1 5	6 10	3 8½	—	—
	Wood	Field	—	—	—	—	—	—	—	0 16	¶ 10¾
12-pr., 8 ,,	,,	Field	—	—	—	—	—	—	—	—	—
9-pr., 6 ,,	,,	Field	—	—	—	—	—	—	—	—	—

* Elevation from bed, with screw removed.
† C pivot.
‡ D pivot.
§ E pivot.
‖ F pivot.
¶ Weight of limber, without stores.
G above the ground. P above the top of pedestal.

Ordnance.	Mark.	Material.	Weight.	Service.	Total Length.	Bore.		Chamber.		
						Calibre.	Length in Calibres.	Diameter in Inches.	Length in Inches.	Capacity in Cubic Inches.
Guns.					ins.	ins.				
17·72-in.	I	W.I. with steel tube	100 tons	L	391·85	17·72	20·48	19·7	59·72	17049
16-in.	I	,,	80 ,,	C	321·0	16·0	18·0	18·0	59·6	14600
12·5-in.	I	,,	38 ,,	C	230·0	12·5	15·84	Unchamb'd	...	...
12·5-in.	II	,,	38 ,,	C	222·8	12·5	15·84	14·0	41·125	6000
12-in., 35-ton	I	,,	35 ,,	C	195·0	12·0	13·54	Unchamb'd	...	...
12-in., 25-ton	II	,,	25 ,,	C	182·5	12·0	12·09	,,	...	...
11-in.	II	,,	25 ,,	C	180·0	11·0	13·18	,,	...	...
10·4-in.	I	,,	28 ,,	L	289·0	10·4	26·00	12·5	56	6666
10-in.	I, II	,,	18 ,,	C	180·0	10·0	14·55	Unchamb'd	...	...
10-in. ...	*III, IV / 9-in. I, 9in. II, 9-in. III	,,	12 ,,	L	145·75	10·0	12·5	,,	...	...
9-in.	I—V	,,	12 ,,	C	156·0	9·0	13·89	,,	...	...
9-in. ...	VIA / I, II, III, IV & V / VIB VIC / V I	,,	12 ,,	L	145·75	9·0	13·89	,,	...	...
8-in. ...	I III	,, ,,	9 ,,	L C	144·0	8·0	14·75	,,	...	...
7-in., 7-ton ...	I—IV	,,	7 ,,	L	148·0	7·0	18·0	,,	...	...
7-in., 6½-ton	I III	,,	6½ ,,	C	133·0	7·0	15·86	,,	...	...
7-in., 90-cwt.	I	,,	90 cwt.	N	131·0	7·0	15·86	,,	...	...
6·6-in.	I	,,	70 ,,	L	118·0	6·6	14·78	6·8	21·0	707
80-pr., 80-cwt.†	—	,,	80 ,,	L	—	—	—	—	—	—
80-pr.	I	Cast-iron, W.I. tube	5 tons	L	136·55	6·29	18·004	Unchamb'd	...	...
64-pr., 64-cwt.	I II	W.I., steel or W.I. tube	64 cwt.	L	119·5 120·0	6·3	15·47	,,	...	...
64-pr., 64 cwt.	III	W.I., steel tube ...	,, ,,	C	118·0	6·3	15·47	,,	...	...
64-pr., 71-cwt.	I	Cast-iron, W.I. tube	71 ,,	C	122·72	6·29	16·42	,,	...	...
64-pr., 58-cwt.	I	,,	58 ,,	L	127·45	6·29	17·24	,,	...	...
40-pr. ...	I II	W.I., steel tube ,,	34 ,, 35 ,,	L L	100·5 120·0	4·75 4·75	18·0 22·0	,, ,,	... ...	... ...
25-pr.	I	,,	18 ,,	L	98·0	4·00	22·0	,,	...	...

* These guns are the 9-inch Marks I, II, and III bored up to 10 inches, for H.A. fire.
† For Victoria, Australia, only.

Rifling.				Vent.§	Ballistic Effects with Full Charges.				Ordnance.
System.	Twist in Calibres.	Length in Inches.	No. of Grooves.	Position. Ins. from end of Bore.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron in Inches. At 1,000 yds.	Penetration of Wrought Iron in Inches. At 2,000 yds.	
									Guns.
Polygroove (plain section)	I. 1 in 150 to 1 in 50, at 288 in. from muzzle, remainder U.	302·88	28	Axial	1548	33233	23	21	17·72-in.
"	I. 0 to 1 in 50 cals.	227·4	33	Axial	1540	27950	23	22	16-in.
Woolwich	I. 0 to 1 in 35 cals	170·5	9	12·0	1442	11823	16	15	12·5-in. I.
"	I. 1 in 438 to 1 in 35 cals. ...	156·87	9	Axial	1575	14140	17·5	16	12·5-in. II.
"	I. 0 to 1 in 35 cals.	135·0	9	12·0	1340	8890	14	13	12-in., 35 tons.
"	I. 1 in 100 to 1 in 50 cals. ...	127·0	9	9·8	1292	7124	12	11	12-in., 25 tons.
"	I. 0 to 1 in 35 cals.	119·0	9	10·0	1360	7830	13	12	11-in.
Polygroove (plain section)	I. 1 in 200 to 1 in 40 cals. ..	213·4	21	Axial	1810	10500	17	15	10·4-in.
Woolwich	I. 1 in 100 to 1 in 40 cals. ...	118·0	7	11·0	1379	5406	12	10	10-in., I, II.
Polygroove (plain section)	{ I. / II. } 1 in 100 to 1 in { 35 cals. / 30 ,,	101·3 —	32 —	2·5 —	— —	— —	— —	— —	10-in.,* III. 10-in.,* IV.
Woolwich	I. 0 to 1 in 45 cals.	104·0	6	9·7	1440	3695	10	9	9-in., I—V.
Polygroove (plain section)	I. 1 in 100 to 1 in 35 at 22·5 in. from muzzle, remainder U.	98·0	27	2·5	1194	—	—	—	9-in. { VIA / I, II, III, IV & V; VIB / V; VIC / I
Woolwich	I. 0 to 1 in 40 cals.	{ 102·0 99·5	} 4	9·2	1390	2391	8	7	8-in., I, III.
"	U. 1 in 35 cals....	110·5	3	8·6	1561	1943	8	6	7-in., 7 tons, I—IV.
"	U. 1 in 35 cals....	95·535	3	8·6	1525	1854	8	6	7-in., 6½ tons, I, III.
"	U. 1 in 35 cals....	95·535	3	8·6	1325	1400	7	6	7-in., 90 cwt.
Polygroove (plain section)	I. 1 in 100 to 1 in 35 at 13·2 in. from muzzle, remainder U.	76·5	20	5·2	1416	1398	—	—	6·6-in.
"	—	—	—	—	1553	1337	—	—	80-pr., 80 cwt.
Woolwich	U. 1 in 40 cals....	106·25	3	1·85	1230	944	—	—	80-pr.
‡Shunt or plain	U. 1 in 40 cals....	90·5	3 {	5·2 or 6·1 5·2	1125	588	—	—	64-pr., 64 cwt., I, II
Plain	U. 1 in 40 cals....	90·5	3	5·2	1390	897	—	—	64-pr., 64 cwt., III.
"	U. 1 in 40 cals....	96·27	3	1·7	1260	737	—	—	64-pr., 71 cwt.
"	U. 1 in 40 cals....	101·45	3	1·3	1260	737	—	—	64-pr., 58 cwt.
Woolwich ... ... "	U. 1 in 35 cals.... ... ... U. 1 in 35 cals....	71·5 90·5	3 3	0·6 1·0	1340 1425	473 555	— —	— —	40-pr., { I. II.
"	U. 1 in 35 cals....	78·0	3	1·0	1350	322	—	—	25-pr.

‡ 64-pr. Mark I guns with shunt rifling will be condemned when they come to the Arsenal.
§ Radial, unless otherwise stated.

ORDNANCE.	Mark.	Material.	Weight.	Service.	Total Length.	Bore.		Chamber.		
						Calibre.	Length in Calibres.	Diameter in Inches.	Length in Inches.	Capacity in Cubic Inches.
					ins.	ins.				
16-pr.	I	W.I., steel tube ...	12 cwt.	L	78·0	3·6	19·0	Unchamb'd	...	...
13-pr.	I	,,	8 ,,	L	92·0	3·0	28·0	3·15	14·13	110·38
9-pr., 8-cwt.	I II	,, ,,	,, ,,	L N	72·0	3·0	21·17	Unchamb'd	...	...
9-pr., 6-cwt. ...	I	,,	6 ,,	N	61·0	3·0	17·67	,,	...	...
9-pr., 6-cwt.	II & III IV	,, Steel	,, ,,	C N	74·5 74·875	3·0	22·0	,,	...	...
2·5-in. (jointed)	I & II	,, ...	400 lb.	L	70·45	2·5	26·6	2·56	11·07	54
7-pr. (bronze) 200-lb.	II	Bronze	200 ,,	N	38·125	3·0	10·7	Unchamb'd	...	...
7-pr., 200-lb....	IV	Steel	,, ,,	C	41·0	3·0	12·0	,,	...	...
7-pr., 150-lb....	III	,, ...	150 ,,	L	29·125	3·0	8·0	,,	...	...
HOWITZERS.										
8-in., 70-cwt.	I II	W.I., steel tube Steel	70 cwt.	L	113·0	8·0	12·0	,,	...	...
8-in., 46-cwt...	I	W.I., steel tube ..	46 ,,	L	64·0	8·0	6·0	,,	...	...
6·6-in. ...	I II	,, ,, Steel	36 ,,	L	90·7	6·6	12·0	,,	..	...
6·3-in.	I	W.I., steel tube ...	18 ,,	L	56·0	6·3	7·14	,,	...	...
4-in. (jointed)	I	Steel	600 lb.	L	57·45	4·0	13·0	,,	...	...

Rifling. System.	Rifling. Twist in Calibres.	Rifling. Length in Inches.	Rifling. No. of Grooves.	Vent.‡ Position. Ins. from end of Bore.	Ballistic Effects with Full Charges. Muzzle Velocity in Foot Seconds.	Ballistic Effects with Full Charges. Muzzle Energy in Foot Tons.	Penetration of Wrought Iron in Inches. At 1,000 yds.	Penetration of Wrought Iron in Inches. At 2,000 yds.	Ordnance.
									Guns.
French, modified	U. 1 in 30 cals....	58·4	3	0·6	1355	203	—	—	16-pr.
Polygroove (plain section)	I. 1 in 100 to 1 in 30 at 9 in. from muzzle, remainder U.	69·0	10	7·0	1595	229	—	—	13-pr.
French, modified	U. 1 in 30 cals....	59·8	3	0·6	1330	119	—	—	9-pr., 8 cwt
,, ...	U. 1 in 30 cals....	49·3	3	0·6	1250	97	—	—	9-pr. 6 cwt., I.
,, ...	U. 1 in 30 cals....	62·3	3	0·6	1330	121	—	—	9-pr., 6 cwt., II, III, IV.
Polygroove (plain section)	I. 1 in 80 to 1 in 30 at 3·53 in. from muzzle, remainder U	54·73	8	5·25	1440	100	—	—	2·5-in., jointed.
French	U. 1 in 20 cals....	29·5	3	·75	914	40	—	—	7-pr., bronze, 200 lb.
,, ...	U. 1 in 20 cals	34·0	3	1·0	950	47	—	—	7-pr., 200 lb.
,, ...	U. 1 in 20 cals....	22·0	3	1·0	673	23	—	—	7-pr., 150 lb.
									Howitzers.
Polygroove (plain section)	I. 1 in 90 to 1 in 35 cals. ...	88·0	24	2·0	956	1150	—	—	8-in., 70 cwt.
Woolwich	U. 1 in 16 cals....	35·5	4	1·75	637	608	—	—	8-in., 46 cwt.
Polygroove (plain section)	I. 1 in 94 to 1 in 35 cals. ...	74·125	20	1·5	839	488	—	—	6·6-in.
,, ...	I. 1 in 100 to 1 in 35 cals. ...	39·7	20	1·125	751	285	—	—	6·3-in.
,, ...	I. 0 to 1 in 25 at 8·3 in. from muzzle, remainder U.	47·0	13	1·0	835	97	—	—	4-in., jointed.

‡ Radial, unless otherwise stated.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).

Ordnance.	Carriages. Material.	Carriages. Nature.	Elevation in Degrees.	Depression in Degrees.	Slides. Material.	Slides. Nature.	Radii of Racers. Front.	Radii of Racers. Rear.	Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated).	Weight. Carriage.	Weight. Slide.
							ft. in.	ft. in.	ft. in.	tons. cwt	tns. ct.
GUNS. 17·72-in., 100 tons	Iron	... ...	11	11	Iron	—	11 4	11 4	10 0	20 7	25 14½
16-in., 80 tons	,,	... ...	7	2	,,	—	—	—	6 5⅜	—	—
12·5-in., 38 tons	,,	7-ft. recoil, small port	7	4	,,	7-ft. recoil, small port	10 2	21 2	†4 7½	10 6¾	7 10
		6-ft. recoil, small port	7	4	,,	6-ft. recoil, small port	10 2	20 2	‡5 9¼	9 13¾	8 9¼
		7-ft. recoil, casemate	10	5	,,	7-ft. recoil, casemate	10 2	21 2	4 11¼	6 3½	8 3½
		6-ft. recoil, casemate or dwarf	10	5	,,	6-ft recoil, casemate	10 2	20 2	4 11¼	6 2¼	8 2¼
						Dwarf, "C"... ...	5 8	5 8	6 0¼		9 8½
						6-ft. recoil, casemate, Mark III special	10 2	21 2	4 11¼		8 3
						Dwarf, "D"... ...	8 0	3 8	6 0¼		9 4½
						7-ft parapet, "C" converted casemate, Mark II, special	5 8	5 8	6 0¼		9 19¾
						7-ft. parapet, "C" converted dwarf "C"	5 8	5 8	6 0		11 18
		Converted small port	15*	5	,,	"C," converted small port	5 8	5 8	7 0½	—	—
12-in., 35 tons	,,	Dwarf	10	5	,,	Dwarf "C"	5 8	5 8	6 0¼	5 15¼	9 6¾
12-in., 25 tons	,,	Casemate or dwarf	15	5	,,	Casemate to work within length	8 0	18 0	4 11½	3 7¾	5 12
11-in., 25 tons	,,					Casemate side or rear	8 0	18 0	4 11½		5 15
						Dwarf "A" (rear)	8 0	18 0	6 3		6 19¼
						Dwarf "C," central or side	5 8	5 8	6 3		7 2½
						7-ft. parapet C ...	5 8	5 8	—		7 2½
10·4-in., 28 tons	,,	Barbette	15	4½	,,	Barbette	—	12 10⅜	9 1½	6 1	7 8
10-in., 18 tons	,,	Casemate or Dwarf (Mark I)	10	5	,,	Casemate Side or rear	8 0	18 0	4 2½	2 11¼	4 15½
						Casemate To work within length Mark I			4 2½		4 17¼
						Dwarf A side or rear			6 0		6 14¼
						Dwarf C central or side	5 8	5 8	6 0		7 0½
						Dwarf D central or side	9 0	3 0	6 0		7 1
						7-ft. parapet, C, Mark I	5 8	5 8	6 2		7 10¼
		Casemate low (Mark II)	10	5	,,	Casemate Mark II	8 0	18 0	4 2½	3 7	5 4
						Casemate To work within length Mark II			4 2½		5 4
						Casemate To work within length Spec.			4 11½		6 5
		Mark III	15	5	,,	7-ft. parapet, C, Mark II	5 8	5 8	6 0·3	3 0½	8 12¼
		Small port	9	4	,,	Small port	8 0	18 0	†4 6¾ ‡5 6¾	6 0	5 6
10-in., 12 tons	,,	High angle Mark III	70	—	—	—	4 4	4 4	6 6	16 13½	—
		High angle Mark IV	70	—	—	—				17 9⅝	—

* Not more than 10° to be given when firing full charges.
† Least height.
‡ Greatest height.

Ordnance	Carriages. Material	Carriages. Nature.	Elevation in Degrees.	Depression in Degrees.	Slides. Material	Slides. Nature.	Radii of Racers. Front	Radii of Racers. Rear.	Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated.)	Weight. Carriage.	Weight. Slide.
							ft. in.	ft. in.	ft. in	tons. cwt	tns. ct.
9-in., 12 tons	Iron	Casemate or dwarf, Mark I	10	5	Iron	Casemate to work within length	6 3	16 6	4 1½	2 2¼	3 14¾
						Dwarf, A pivot, rear			5·9		4 17
						Dwarf, C pivot, central	5 5¾	5 5¾	5 9		5 10
						Dwarf, D pivot ...	9 0	2 3¾	5 9		5 7
						7-ft. parapet, C pivot, Mark I	5 5¾	5 5¾	5 9		6 1
		Converted Naval, single plate	12	9	,,	Converted Naval slide	5 1	13 6	4 1	2 4	3 0
		Garrison, Mark II	20	12	,,	7-ft. parapet, C pivot, Mark III	5 5¾	5 5¾	5 9	2 8	8 8¼
						7-ft. parapet, C pivot, Mark IV	5 5¾	5 5¾	5 9		8 8¼
		High Angle Mark I	70	—	—	—	4 9	4 9	9 6½	20 16	—
		High Angle ,, II	70	—	—	—	5 5¾	5 5¾	8 10¾	—	—
		High Angle ,, III	70	—	—	—	4 4	4 4	6 6	16 13½	—
		High Angle ,, IV	70	—	—	—				17 9¼	—
8-in., 9 tons	,,	Converted Naval, single plate	12	9	Iron	Converted Naval slide	—	—	3 9½	1 19¾	2 15¼
		Elevation	16	9	,,	Elevation	4 7½	13 7	3 5¼	1 19	2 15½
7-in., 7 tons	,,	Casemate or dwarf	20	5	,,	Casemate	6 3	16 6	4 1¼	1 7¾	2 13
						Dwarf, A pivot ...	6 3	16 6	5 8¾		3 17¾
						,, C ,, ...	5 5¾	5 5¾	5 8¾		4 0¾
						,, D ,, ...	9 0	2 3¾	5 8¾		4 0¾
		Moncrieff, Mark I	15	5	—	—	8 3½	5 8½	10 11¾	22 3½	—
		,, ,, II	15	5	—	—	9 10	5 7½	12 3½	22 18	—
7-in., 6½ tons	,,	Converted Naval, S plate	13§	7	Iron	Dwarf, C pivot ...	—	—	5 8	1 7½	4 0¾
						,, D ,, ...	—	—	5 8		4 0¾
		Converted Naval, D plate, with hydraulic buffer	15	7	,,	Converted slide, 4° slope, for hydraulic buffer	5 1	13 6	3 5	1 12	1 19
		Converted Naval, with compressor gear	15	7	,,	Converted slide, 4° slope, with compressor gear			3 4¼	1 7¼	1 17¼
		Iron sliding medium, No. 7	30	5	,,	Traversing medium, No. 7, 6-ft. parapet	6 1	6 1	7 1	2 14¼	3 15¼
6·6-in., 70 cwt.	Steel	Siege (H.P.)	12	5	—	—	—	—	8 5½G	2 12⅕	—
80-pr. (convd.) 5 tons	Wood	Sliding medium, No. 21	7§	5	Wood	Traversing medium, No. 14, casemate	5 0	16 6	3 6¾	0 15¼	1 7
	,,	Sliding medium, No. 22	18§	5	,,	Traversing medium, No. 16, dwarf C	6 1	6 1	5 2	0 15¾	1 17
						D	9 3	3 4¼			
						E	10 8¼	2 2			
						F	12 10	2 2			
						Traversing medium, No. 18, 6-ft. parapet C	6 1	6 1	7 1		2 13
						D	9 3	3 4¼			
						E	10 8¼	2 2			
						F	12 10	2 2			
64-pr., 64-cwt.	Iron	Common, standing No. 1	—	—	—	—	—	—	3 5½G	0 17¼	—
	Wood	Common, standing Wood	16	12	—	—	—	—	3 2¼G	0 14¾	—
	Iron	Sliding, medium, No. 8	15	5	Iron	Traversing medium, No. 8, 6-ft. parapet A	5 0	16 6	7 0	1 14¾	3 9¾
						C	6 1	6 1			
						E	10 8¼	2 2			
						F	12 10	2 2			
	,,	Sliding, medium, No. 9	15	5	,,	Traversing medium, No. 9, 5-ft. 6-in. parapet C	6 1	6 1	6 6	1 7	2 18
						D	9 0	3 4¼			
						E	10 8¼	2 2			
						F	12 10	2 2			

§ Elevation from bed, with screw removed. The letters A, B, C, D, E and F refer to the nature of pivot.
G Above the ground.

Ordnance.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.			Radii of Racers.		Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated).	Weight	
	Material	Nature.			Material	Nature.		Front	Rear.		Carriage.	Slide.
Guns.								ft. in.	ft. in.	ft. in.	tns. ct.	tns. ct.
64-pr., 64 cwt.	Iron	Sliding medium, No. 26	15	5	Iron	Traversing medium, No. 21, 6-ft. parapet	A C E F	5 0 6 1 10 8¼ 12 10	16 6 6 1 2 2 2 2	6 11½	1 18	3 8½
	Steel	Sliding medium, No. 27	11½	0	,,	Traversing medium, No. 23		3 0	10 2¼	3 6	1 0½	1 1¾
	,,	Sliding medium, No. 28	11½	10	,,	Traversing medium, No. 24		3 0	10 11¾	3 4	1 2	1 0½
64-pr., 71 and 58 cwt.	Iron	Sliding medium, No. 10	15	5	Wood	Traversing medium, No. 11, dwarf	C D E F	6 1 9 0 10 8¼ 12 10	6 1 3 4¼ 2 2 2 2	5 1¾	1 3	2 4
						Traversing medium, No. 12, casemate	A	5 0	16 6	4 6¼		1 14¾
	Wood	Sliding medium, No. 23	20§	5	,,	Traversing medium, No. 16, dwarf	C D E F	6 1 9 3 10 8¼ 12 10	6 1 3 4¼ 2 2 2 2	5 1	0 12½	1 17
						or No. 17 ..	A	5 0	16 6	5 1		1 17
						Traversing medium, No. 18, 6-ft. parapet	C D E F	6 1 9 3 10 8¼ 12 10	6 1 3 4 2 2¼ 2 2	7 0		2 13
64-pr., 71 cwt.	Iron	Common, standing, No. 1	20	5	—	—		—	—	3 4½σ	0 17¼	—
	Wood	Common, standing, Wood	17§	—	—	—		—	—	3 4½σ	0 8¾	—
	Iron	Sliding medium, No. 11	15	8	Wood	Traversing medium, No. 13, casemate		5 0	14 0	4 6	1 4½	1 10¾
	,,	Sliding medium, No. 12	12	8½	,,	Traversing medium, No. 19, 2-ft. 7-in. parapet		5 0	16 6	3 10	1 3	1 13¼
	,,	Sliding medium, No. 10	15	5	,,	Traversing medium, No. 20, 6-ft. parapet	A	5 0	16 6	7 0	1 8	3 3
64-pr., 58 cwt.	Iron	Common, standing, No. 2	21½	6	—	—		—	--	3 4½σ	0 17¼	—
	Wood	Common, standing, Wood	17§	6	—	—		—	—	3 4½σ	0 14¾	—
	,,	Depression	—	30	—	—		—	—	3 4½σ	0 16	—
	Iron	,, ...	—	32	—	—		—	—	3 7σ	1 9¼	—
	Wood	,, No. 25	10§	6	Wood	Traversing medium, No. 14, or 22, casemate	A	5 0	16 6	3 6½	0 11	1 7
	Iron	,, No. 13	15	5	,,	Traversing medium, No. 11 or 12 (*see* "R.B.L. Carriages & Slides")		—	—	—	1 2½	—
	,,	Moncrieff, with platform	10½	5	—	... ...	C D	6 10 8 11	6 10 4 8½	10 5	11 9	—
40-pr., 34 and 35 cwt.	,,	Sliding medium, No. 14	10	8	Iron	Traversing medium, No. 10, casemate	A	5 0	14 0	3 6	0 11½	1 4¼
												Weight of limber
		Siege, Mark I ...	35	5	—	—		—	—	4 5σ	1 7	0 13¼
		,, ,, II ...	35	5	—	—		—	—	4 5σ	1 12½	0 13¼
		Top, overbank ...	35	5	—	—		—	—	6 3σ	*0 10½	—
25-pr., 18 cwt.	,,	Field	45	5	—	—		—	—	8 10σ	0 15	0 11¼
		Siege, top, overbank	35	5	—	—		—	—	6 0σ	*0 8½	—

* Weight of top carriage only. § Elevation from bed, with screw removed. σ Above the ground.
The letters A, B, C, D, E, and F refer to the nature of pivot.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).—Continued.

Ordnance.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.		Height of Axis of Trunnions above the Racer in Firing Position (except where otherwise stated).	Weight.	
	Material	Nature.			Material	Nature.	Front	Rear.		Carriage.	Slide.
GUNS.							ft. in.	ft. in.	ft. in.	tns. ct.	tns. ct.
16-pr., 12 cwt.	Iron	Mark I, strengthened	22½	12¼	—	—	—	—	3 7½G	0 13½	0 11⅓
	Iron	Mark II	17	15	—	—	—	—	3 7¼G	0 13	0 11
15-pr. jointed, 422 lbs.	Steel	Mountain, Mark I	25	10	—	—	—	—	2 1½G	0 3¾	—
13-pr., 8 cwt.	,,	Field	16	5	—	—	—	—	3 7 G	0 12	0 12
9-pr., 8 and 6 cwt.	Iron	Mark I, strengthened	21	4	—	—	—	—	3 6½G	0 12⅘	0 11⅖
	Iron	Mark II...	22	6	—	—	—	—	3 6½G	0 11⅘	0 11⅓
2·5-in., jointed, 400 lbs.	Steel	Mountain, Marks II, III, and IV	25	15	—	—	—	—	2 1¾G	0 4¾	—
7-pr. 200 lbs.	Iron	Field	35	10	—	—	—	—	3 8¾	0 9¼	0 9¼
	,,	Mountain	33	8	—	—	—	—	2 1¾	0 3⅛	0 3⅖
	,,	Bed...	22	5	—	—	—	—	1 2¼	0 2	—
7-pr. 150 lbs.	,,	,, ...	45	5	—	—	—	—	1 10	0 2¾	—
	Steel	Gold Coast	20	5	—	—	—	—	2 0	0 3⅛	—
	Wood	,, ...	20	5	—	—	—	—	2 0	C 2½	—
HOWITZERS											
8-in., 70 cwt.	Iron	Siege, 70 cwt. ...	35	5	—	—	—	—	4 5	2 4	*0 12$\frac{1}{10}$
	,,	Siege, 46-cwt. converted	—	—	—	—	—	—	—	—	—
8-in., 46 cwt.	,,	Siege, 46-cwt. ...	30	—	—	—	—	—	4 8¼	2 11½	*0 12$\frac{1}{10}$
	,,	Bed...	45	—	—	—	—	—	2 6	1 13	—
6·6-in., 36 cwt.	,,	Siege	35	5	—	—	—	—	4 5	1 18	*0 12$\frac{1}{10}$
	Steel	Bed...	45	—	—	—	—	—	3 0½	1 11	—
6·3-in., 18 cwt.	Iron	Siege	40	5	—	—	—	—	4 5	1 17½	*0 12$\frac{1}{10}$
	Steel	Bed	70	—	—	—	—	—	3 0½	1 11¼	—
4-in., jointed, 600 lbs.	,,	Mountain	36	7	—	—	—	—	2 2⅞	0 5⅓	—

* For siege train, 12¾ cwt.

G Above the ground.

QUICK-FIRING ORDNANCE

Ordnance.						Bore.		Ballistic Effects.			
										Penetration of Steel Plate in Inches.	
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Inches.	Calibre in Inches.	Length in Inches.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	At Muzzle.	At 1,000 yards.
Q.F. 6-inch and 6-inch B	I, III,	Steel	7 tons	N	249·25	6·0	240·0	a1882	2458	9·4	8·0
	II	Steel (wire construction)	,,	C				b2200	3356	11·1	9 0
Q.F.C. 6-inch ...	$\frac{I}{IV}$ & $\frac{I}{VI}$, $\frac{II}{IV}$ & $\frac{II}{VI}$, $\frac{III}{IV}$ & $\frac{III}{VI}$	Steel	5 tons	N	169·1	6·0	159·85	1913	—	—	—
	$\frac{II}{III}$ & $\frac{III}{III}$	,,	5 ,,	N	166·55	6·0	157·3	1913	—	—	—
Q.F. 4·7-inch, 4·7-inch cA, B, and D.	I	Steel	41 cwt.	N	194·1	4·724	189·0	a1786	995	6·7	5·4
	II, III	,,	,,	C				b2188	1494	8·4	7·7
	III*	,,	,,	L							
	IV	Steel (wire construction)	42 cwt.	C							
	V	Steel	53 ,,	L	212·6	4·724	207·5	2570	2061	15·3	—

a With powder charge. *b* With cordite charge at 80° F. *c* Q.F. 4·7-inch A guns are Naval only.

MACHINE GUNS.

(Q.F. AND Q.F.C.).

Rifling.							Fuzes.		Ordnance.	
System. Polygroove.	Mark.	Twist.	Length in Inches.	Grooves. Number.	Grooves. Width in Inches.	Grooves. Depth in Inches.	Time.	Percussion.	Nature.	Mark.
Hook section	I	From 1 turn in 60 calibres at breech to 1 in 30 at muzzle	214·7	24	0·6	0·05		Base, large, No. 11	Q.F. 6-in. and 6-in. B	I, III,
Modified plain section	*II	Straight from breech end of rifling to 178·7 inches from the muzzle, the remaining 178·7 inches increasing from 0 to 1 turn in 30 calibres at muzzle			0·39					II
Hook section	II	From 1 turn in 63·86 calibres at breech end of rifling to 1 turn in 30 calibres at muzzle, being the existing rifling of the gun extended 7·385 inches to the rear with the same increasing twist	134·26		0·6				Q.F.C. 6-inch	$\frac{I}{IV}$ & $\frac{I}{VI}$, $\frac{II}{IV}$ & $\frac{II}{VI}$, $\frac{III}{IV}$ & $\frac{III}{VI}$, $\frac{II}{III}$ & $\frac{III}{III}$
Modified plain section	*III	Straight from breech end of rifling to 108 inches from the muzzle, the remaining 108 inches increasing from 0 to 1 turn in 30 calibres at muzzle	131·46		0·39					
Elswick section	I	From 1 turn in 100 calibres at breech to 1 in 34·352 at 6·65 inches from the muzzle, remainder uniform 1 in 34·352	171	22	0·5	0·04	T. and P., No. 56		Q.F. 4·7in., 4·7in. A, B, and D	I, II, III, III*, IV
Modified plain section	*II	Straight from breech end of rifling to 142·656 inches from the muzzle, the remaining 142,656 inches increasing from 0 to 1 turn in 30 calibres at muzzle			0·45					
Plain section	—	Straight from breech end of rifling to 150·866 inches from muzzle, then increasing from 0 to 1 turn in 30 calibres at 8·21 inches from muzzle, the remaining 8·21 inches being uniform 1 in 30 calibres	179·21	26	*d* 0·371, *e* 0·321			Base, medium, No. 12		V

d At the breech end. *e* At the muzzle end.

* For guns of future manufacture, and for existing guns when repaired with new A tubes or through lined.

Ordnance.						Bore.		Ballistic Effects.			
										Penetration of Steel Plate in Inches.	
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Inches.	Calibre in Inches.	Length in Inches.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	At Muzzle.	At 1,000 yards.
Q.F. 4-inch ...	I, IA, IB, I/III	Steel (wire construction)	26 cwt.	N	165·25	4·0	160·0	b2456	1046	7·6	5·4
	II	,,	,,	N							
	III	,,	,,		165·35						
Q.F.C. 4 inch ...	I/IIIA, I/IV, I/V, I/VI	Steel	26 cwt.	N	120·0	4·0	111·4	2177	—	—	—
Q.F. 12-pr., 12 cwt. A.	I	Steel	12 cwt.	C	123·6	3·0	120·0	b2210	423·4	5·6	4·0
Q.F. 12-pr., 8 cwt.		,,	8 cwt.	N	87·6	3·0	84·0	b1607	2238	3·9	2·8

b With cordite charge at 80° F.

Rifling.							Fuzes.		Ordnance.	
System. Polygroove.	Mark	Twist.	Length in Inches.	Grooves. Number.	Grooves. Width in Inches.	Grooves. Depth in Inches.	Time.	Percussion.	Nature.	Mark.
Plain section	I	Straight from the breech end of rifling to 120 inches from the muzzle, the remaining 120 inches increasing from 0 to 1 turn in 30 calibres at muzzle	143·456	24	*d*0·35 *e*0·315	0·06	T. and P., No. 56	Base, large, No. 11	Q.F. 4-inch	I, IA, IB; II
Modified plain section	*II				0·28					
Hook section	II	From 1 turn in 224·7 calibres at breech end of rifling to 1 turn in 30 calibres at 43·77 inches from the muzzle, the remaining 43·77 inches having a uniform twist of 1 turn in 30 calibres; the rifling of the converted gun being the existing rifling of the B.L. gun extending 6·836 inches to the rear with the same increasing twist	94·606		0·4			Base, medium, No. 12	Q.F.C. 4-inch	III; I/IIIA, I/IV, I/V, I/VI
Modified plain section	*III	Straight from breech end of rifling to 72 inches from the muzzle, the remaining 72 inches increasing from 0 to 1 turn in 30 calibres at muzzle			0·28	0·04				
Elswick section	I	From 1 turn in 120 calibres at breech to 1 in 28 at muzzle	103·315	16	0·4				Q.F. 12-pr. 12 cwt. A	
Modified plain section	*II	Straight from breech end of rifling to 85·035 inches from the muzzle, the remaining 85·035 inches increasing from 0 to 1 turn in 30 calibres at muzzle			0·365					
Elswick section	I	From 1 turn in 60 calibres at breech to 1 in 28 at muzzle	74·81		0·4				Q.F. 12-pr. 8 cwt.	I
Modified plain section	*II	Straight from breech end of rifling to 56·81 inches from the muzzle, the remaining 56·81 inches increasing from 0 to 1 turn in 30 calibres at muzzle			0·365					

d At the breech end. *e* At the muzzle end.

* For guns of future manufacture, and for existing guns when repaired with new A tubes or through lined.

Machine Guns. Nature.	Calibre.	Number of Barrels.	Mark and Letters.	Service.	Weight of Gun complete with Distributor and Feed Guide or Cartridge Feeder, but without Mounting or Shield.	Total Length.	Sighted up to.	Length of Barrels.	Rifling. System.	Rifling. Pitch.	Rifling. Length.	Rifling. Number of Grooves.
	in.				lb.	in.	yds.			1 in.	in.	
Nordenfelt	1·0	2	I	N	180	52·0	3000	35·48	Henry	35	31·39	11
"	1·0	4	I	N	440	57·0	3000	35·48	"	60	31·39	11
"	1·0	4	II	N	440	57·0	3000	35·48	"	35	31·39	11
"	1·0	4	III	N	447	57·0	3000	35·48	"	35	31·39	11
Nordenfelt, converted from 0·45-inch M.H.	0·303	3	I	L	110	41·5	2300	28·5	Enfield	10	26·25	5
Nordenfelt	0·45	5	I G.G.	N*	160	46·0	2000	28·5	Henry	22	25·6	7
"	0·45	5	II G.G.	N*	143	42·25	2000	28·5	"	22	25·6	7
Gardner...	0·45	1	I G.G.	N	76	47·0	2000	30·0	"	22	27·1	7
"	0·45	2	I G.G.	N*	120	47·0	2000	30·0	"	22	27·1	7
Gardner, converted from 0·4-inch and 0·45-inc M.H.	0·303	2	I	L	92	45·0	2500	28·25	Enfield	10	26·0	5
Gardner...	0·45	5	I G.G.	N*	268	53·5	2000	33·0	"	22	30·1	7
Gatling	0·65	10	—	N	787	66·5	2000	33·0	†	30	28·1	7
"	0·45	10	I G.G.	N*	402	59·0	2000	31·95	Henry	22	29·0	7
Gatling, "Accles' Field"	0·45	10	I G.G.	N	266	51·0	2000	32·0	"	22	29·1	7
Maxim	0·45	1	I G.G.	N	60	43·75	2000	29·2	"	22	26·31	7
Maxim, converted from 0·45-inch M.H.	0·303	1	I	L	64	45·0	2500	29·2	Enfield	10	27·0	5
Maxim	0·303	1	I	C	60	42·375	2500	28·375	Metford *a* Enfield	10	25·625 27·0	7 5

a These guns in future will be rifled on the Enfield system.
† No name has been given to this system of rifling.

* The use of these guns in L.S. is quite exceptional. It is described in § 3325, List of Changes.

Weight of Hopper, Drum, Cartridge-Holder, Feed-Box, or Belt.		Number of Cartridges in Hopper, Drum, Cartridge-Holder, Feed-Box, or Belt.	Nature of Ammunition.	Powder Charge.	Projectile.	Penetration.	Nature of Gun.
Empty.	Filled.						
lb. oz. 13 0	lb. oz. 27 0	20	Solid case, steel projectile	grains. 625 M.G.[1] ...	7·25 oz.	Perforates $\frac{3}{4}$-inch steel plate at 200 yards	Nordenfelt, 1·0-in., 2-bl., Mark I
20 0	48 0	40	Solid case, steel projectile	625 ,, ...	7 25 oz.	Perforates $\frac{3}{4}$-inch steel plate at 200 yards	Nordenfelt, 1·0-in., 4-bl., Mark I
20 0	48 0	40	Solid case, steel projectile	325 ,, ...	7·25 oz.	Perforates $\frac{3}{4}$-inch steel plate at 200 yards	Nordenfelt, 1·0-in., 4-bl., Mark II
20 0	48 0	40	Solid case, steel projectile	625 ,, ...	7·25 oz.	Perforates $\frac{3}{4}$-inch steel plate at 200 yards	Nordenfelt, 1·0-in., 4-bl., Mark III
0 12	2 6	27	Solid case, stamped "C."	31 (cordite, size $3\frac{3}{4}$)	215 gr.	Same as L.E. Rifle, which perforates $1\frac{3}{8}$-in. wrought iron plates at 40 yards	Nordenfelt, ·303-in., 3-bl., converted, Mark I
5 2	10 14	50	Gardner-Gatling ...	85 R.F.G.[2]	480 gr.	Same as M.H. Rifle, which perforates $\frac{1}{8}$-inch wrought iron plate at 600 yards, $\frac{3}{16}$-inch plate at 400 yards, and $\frac{1}{4}$-inch at 100 yards	Nordenfelt, ·45-in., 5-bl., Mark I
5 2	10 14	50	,, ,, ...	85 ,, *b*	480 gr.		Nordenfelt, ·45-in., 5-bl., Mark II
0 7	2 12	20	,, ,, ...	85 ,, *b*	480 gr.		Gardner, ·45-in., 1-bl., G.G., Mark I
0 7	2 12	20	,, ,, ...	85 ,,	480 gr.		Gardner, ·45-in., 2-bl., G.G., Mark I
0 10	1 13	20	Solid case stamped "C."	31 (cordite, size $3\frac{3}{4}$)	215 gr.	Same as L.E. Rifle...	Gardner, ·45-in., 2-bl., ·303-in., converted, Mark I
3 5	9 0	50	Gardner-Gatling ...	85 ,, *b*	480 gr.	Same as M.H. Rifle	Gardner, ·45-in., 5-bl., G.G., Mark I
28 8	46 5	50	·65-inch, rolled case	270 R.F.G.[2]	1425 gr.	—	Gatling, ·65-in., Mark I
29 0	56 12	240	Gardner-Gatling ...	85 ,, *b*	480 gr.	Same as M.H. Rifle	Gatling, ·45-in., G.G., Mark I
17 8	29 1	100	,, ,, ...	85 ,, *b*	480 gr.	,, ,,	Gatling, ·45-in. G.G. (Accles), Mark I
4 8 2 0	43 12 18 8	334 140	,, ,, ...	85 ,, *b*	480 gr.	,, ,,	Maxim, ·45-in., G.G., Mark I
2 6	17 0	—	Solid case, stamped "C."	31 (cordite, size $3\frac{3}{4}$)	215 gr.	Same as L.E. Rifle...	Maxim, ·303-in., converted, Mark I
2 6 0 $12\frac{1}{2}$	17 0 5 $13\frac{3}{4}$	250 84	Solid case, stamped "C."	31 (cordite, size $3\frac{3}{4}$)	215 gr.	—	Maxim, ·303-in., Mark I

b A cordite cartridge has been approved, § 8365, for use in all 0·45 machine guns with G.G. chambers.

Ordnance, Q.F.		Projectiles and their Bursting Charges																
		Shells, Filled and Fuzed.																
		Common.			Common Pointed.			Lyddite, Common.			Shrapnel.			Palliser.				
Nature.	Mark.	Mark.	Weight.	Bursting Charge.	Mark.	Weight.	Bursting Charge.	Mark.	Weight.	Bursting Charge.	Mark.	Weight.	Blasting Charge.	Mark.	Weight.	Bursting Charge.	Mark.
			lb. oz. d.	lb. oz. d.		lb. oz	lb. oz. d.		lb. oz	lb. oz. dr.		lb. oz.	oz. dr.		lb.	oz. dr	
Q.F., 6-in.	I, II, III	IIIa, IXa	100 0 0	7 4 6	Ia d	100 0	7 0 0										
					IIa d	100 0	4 2 0 (salt)				IIa	100 8	7 0				
Q.F.C., 6-in.	I, II, III IV & VI	VII*a	100 0 0	6 9 12	Ia d	100 0	4 2 0 (salt)	Ic	102 4	13 12 0	IV c	100 8	10 8	VI	100	24 0	Ib, I
	II, III	Vb	100 0 0	8 14 0	I, II, IIIb	100 0	9 4 0				V, VI*, VII b	100 8½	10 8				
	III	VI*b, VIIIb	100 0 0	9 13 0	IVb	100 0	8 14 0	II, III c	101 2	10 6 0							
Q.F., 4·7-in.	I to V	I, IIa	45 0 0	2 15 8	IV, VIb	45 0	4 3 12	I, IIc	46 9	7 5 0	I, IIc	45 0	5 0	—	—	—	I, I, III, IV, Vc
		IIIb	45 0 0	4 4 0	Va d	45 0	2 11 0										
					VII a d	45 0	1 13 4 (salt)										
Q.F., 4-in.	I, II, III	III VIIIa	25 0 0	1 12 0	Ia d	25 0	1 1 12	I, IIc	25 0	3 3 8	V, VIc	25 0	1 8	III	25	13 8	Ic
Q.F.C., 4-in.	I																
	IV, V, VI, VIA	VIc	25 0 0	3 3 0	I, IIb	25 0	2 0 0										
Q.F., 12-pr., 12cwt., A	I	—	—	—	Ia	12 8	0 3 0	—	—	—	Ia	11 10¼	0 12	—	—	—	†Ic
					Ib	12 8	1 8 0				I, II IIIc	12 8	1 8				†IIc
					II, IIIb	12 8	1 3 0										
Q.F., 12-pr., 8 cwt.	I	—	—	—	Ia	12 8	0 3 0	—	—	—	I, II IIIc	12 8	1 8	—	—	—	—
					Ib	12 8	1 8 0										
					II, IIIb	12 8	1 3 0										
Hotchkiss, 6-pr.	I, II	IIIc to VIIc	6 0 0	0 4 0	—	—	—	—	—	—	—	—	—	—	—	—	—
Nordenfelt, 6-pr.	I, II, III	IIa to Va	6 0 0	0 3 0	—	—	—	—	—	—	—	—	—	—	—	—	—
Hotchkiss, 3-pr.	I, II	IIc to VIc	3 4 12	0 2 0	—	—	—	—	—	—	—	—	—	—	—	—	—
Nordenfelt, 3-pr.	I	IIa to Va	3 4 3½	0 1 6	—	—	—	—	—	—	—	—	—	—	—	—	—
Maxim, 1-pr.	II	—	1 0 0	grains 270	—	1 0	grains 270	—	—	—	—	—	—	—	—	—	—

a Iron. *b* Cast Steel. *c* Forged Steel. *d* Naval. † No more to be made.

GUNS (Q.F. AND Q.F.C.).

Armour-Piercing: Weight.	Armour-Piercing: Bursting Charge.	Mark.	Shot: Armour-Piercing.	Mark.	Palliser.	Mark.	Case.	Description of Ammunition.	Charges: Full: Weight.	Full: Nature.	Reduced: Weight.	Reduced: Nature.	Blank or Saluting: Weight.	Blank or Saluting: Nature.	Ordnance, Q.F.: Nature.	Mark.
lb. oz.	lb. oz. d.		lb.		lb.		lb. oz.		lb. oz. d.		lb. oz. d.		lb. oz.			
								Charge in brass case, with electric primer attached. Projectile separate. Adapter for percussion firing can be substituted for electric primer if necessary.	13 4 0 27 12 0	Cordite size 30 E.X.E. and RLG.[4]	22 0 0 14 0 0	E.X.E. g P.2e	7 0	Blank L.G.	Q.F., 6-in.	I, II, III
100 0 100 0	4 4 0 5 8 0	I, II IIIc	100	IV V	100	—	—		13 4 0	Cordite size 30	5 8 0	Cordite size 10	7 0	,,	Q.F.C., 5-inch	I, II, III IV & VI II, III / III
45 0 45 0	1 15 0 1 12 0	—	—	—	—	—	—		5 7 0 12 0 0 —	Cordite size 20 S.P. —	8 0 0 8 8 0 2 2 8	S.P. g P.2e Cordite size 7½g	3 0	,,	Q.F., 4·7-inch	I to IV
									7 8 0	Cordite size 20	—	—	—	—	,, ,,	V
25 0	0 13 8	—	—	—	—	—	—		3 12 0 3 9 0	Cordite size 15	1 8 0	,, 5	3 0	,,	Q.F., 4-inch Q.F.C., 4-inch	I, II, III I / IV, V, VI / VIA
12 8 12 8	0 9 8 0 6 8	—	—	—	—	IV V	12 14 13 4		1 15 0 1 9 8 4 0 0	Cordite size 15 Cordite size 10 S.P. h	12 8	,, 5	1 8	,,	Q.F., 12-pr 12-cwt. A.	I
—	—	—	—	—	—	IV V	12 14 13 4		0 13 12	Cordite size 10	—	—	1 8	,,	Q.F., 12-pr 8 cwt.	I
—	—	—	—	—	—	—	—	Charge in brass case, with percussion cap in base, and projectile attached as in small arm ammunition.	1 15 0 0 7 12 0 0 4	Q.F.[1] Cordite size 5 R.F.G.[2]	—	—	0 15 0 6 i	,,	Hotchkiss, 6-pr.	I, II
—	—	—	—	—	—	—	—		1 15 0 0 7 12 0 0 4	Q.F.[1] Cordite size 5 R.F.G.[2]	—	—	0 15 0 6 i	,,	Nordenfelt, 6-pr.	I, II, III
—	—	—	—	—	—	—	—		1 8 0 0 6 6 0 0 4	Q.F.[1] Cordite size 5 R.F.G.[2]	—	—	0 11	,,	Hotchkiss, 3-pr.	I, II
—	—	—	—	—	—	—	—		1 8 0 0 6 6 0 0 4	Q.F.[1] Cordite size 5 R.F.G.[2]	—	—	0 1		Nordenfelt, 3-pr.	I
—	—	—	—	—	—	—	—		oz. grains 1 90	Cordite size $\frac{3\cdot75}{2\cdot5}$	—	—	—	—	Maxim, 1-pr.	II

c For practice from gunnery ships, when P2 is available. *f* For practice from gunnery ships, and for land service when specially ordered. *g* For use in gunnery ships only. *h* For paper shot. *i* Special naval service.

MOUNTINGS FOR QUICK-FIRING GUNS.

Ordnance, Q.F.	Nature of Mounting.	Mark.	Service.	Elevation in Degrees.	Depression in Degrees.	Width.	Length. Carriage.	Length. Gun and Carriage.	Height of Axis of Trunnions. From top of Pedestal (except where otherwise stated).	Height of Axis of Trunnions. From Gun Floor.	Weight. Mounting or Carriage without Shield.	Weight. Limber without Stores.
						ins.	ins	ins.	ins.	ins	ct. qr.	ct. qr.
6-inch	... ...	I	L	20	10	—	—	—	42·3	—	78 0½	—
	... ...	II	L	20	10	—	—	—	42·3	—	—	—
4·7-inch B. ...	Central pivot† ...	I*	L	20	10	53	—	—	32·625	—	55 2	—
		II	L	20	10	—	—	—	35	—	50 1	—
		III	L	20	10	—	—	—	45·625	—	—	—
4·7-inch, II, III ...	,, ,, ...	I	L	20	10	53	—	—	32·625	—	55 2	—
12-pr., 12 cwt. ...	Pedestal	I	L	20	5‡	66	51	128	43·5 G	—	18 2½	—
6-pr., Hotchkiss I	Frame stand...	I	C	18	30	41·5	58·25	108·9	—	43	11 1¾	—
6-pr., Hotchkiss II	Recoil embrasure...	I	L	20	20	—	—	—	22·55§	—	8 2¼	—
	Recoil cone	I	L	20	20	—	—	—	43·435G	—	10 3½	—
6-pr., Nordenfelt III	,, embrasure...	I	L	20	20	—	—	—	22·55§	—	9 0	—
	,, cone	I	L	20	20	—	—	—	43·435G	—	10 3	—
3-pr., Hotchkiss I	Elastic frame stand ...	I	C	25	35	—	—	—	—	43	7 0¾	—
3-pr., Hotchkiss I	Recoil	I	L	25	35	—	—	—	—	43	6 2	—
3-pr., Hotchkiss II	Travelling carriage ...	I	L	12	5½	60	97	139·5	41·5 G	—	11 3	10 2¾
3-pr., Hotchkiss II	,, ,, ...	II	L	12	5½	60	97	139·5	41·5 G	—	11 3	9 2
3-pr., Nordenfelt I	Recoil	I	L	25	35	—	—	—	—	43	6 2	—
3-pr., Nordenfelt I	Travelling carriage ...	I	L	15	5½	60	97	139·5	41·5 G	—	11 3	10 2¾
3-pr., Nordenfelt II	,, ,, ...	II	L	15	5½	60	97	139·5	41·5 G	—	11 3	9 2
1-pr., Maxim ... II	,, ,, ...	—	L	16	10	62	112·5	132·0	44·75 G	—	7 1¾	11 2¼

† A travelling carriage is also being considered.
‡ The shield is made to allow of 5 degrees depression only, and must be cut locally where 15 degrees of depression is required.
§ Above sill of embrasure.
G Above ground.

MOUNTINGS FOR MACHINE GUNS.

Nature of Gun.	Mountings.				Carriages.				Remarks.
	Nature and Mark.	Service.	Weight.		Nature.	Service.	Weight.		
			Mounting.	Shield.			Carriage.	Limber.	
			lbs	lbs.			lbs.	lbs.	
Nordenfelt, ·303-in., 3-bl., converted.	—	L	—	—	Field, infantry	L	769	—	Also for 2-bl. Gardner gun
					Field, cavalry or mounted infantry...	L	1036	—	
					Parapet	L	168	—	
Gardner, ·303-in., 2-bl., converted.	—	—	—	—	Field, infantry	L	769	—	Also for 3-bl. Nordenfelt.
					Parapet	L	168	—	
Maxim, ·45-in., G.G.	Cone	C	100	64*					
,, ·303-in. conv. / ,, ·303-in. ...	,,	C	100	64	Parapet	L	172½	—	
					Field, cavalry or mounted infantry..	L	982	—	
					Field, infantry	L	738	—	
,, ·303-in. or ·45-in.	Tripod, Mark I	L	85	—	Field or tripod, infantry, Mark I	L	231	—	Pack transport.
,, ·303 in	Tripod, Mark II	L	56	—	—	—	—	—	
	Tripod, Mark III	L	46	—	—	—	—	—	

* The first 89 shields issued with these guns were of a slightly different pattern, and weighed 54lb. each.