R·E

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PROFESSIONAL PAPERS OF THE ROYAL ENGINEERS.

PAPER I., VOL. XXIX. 1903.

THE ASTROGRAPHIC CHART AND ASTROGRAPHIC METHODS.

(*Lecture delivered at the School of Military Engineering, Chatham, on 8th January*, 1903, *by* H. H. TURNER, D.Sc., F.R.S., *Savilian Professor of Astronomy, Oxford*).

THE ASTROGRAPHIC CHART AND ASTROGRAPHIC METHODS.

AMONG the many achievements of which the Royal Engineers have good reason to be proud there is none which ...

ERRATA.

PAGE 9, first line, second paragraph, between *National Observatory* and *at Oxford* insert "at Greenwich, the University Observatory"

... the measurement of a long arc both astronomically and geodetically, and the size of the earth can only be inferred when we have both these measures. The United States coast survey is indeed extending its operations from both coasts so that they may meet in the interior, and when this work is completed it will form a valuable addition to the material for determining the size of the earth; but unless I am mistaken it is not yet completed. A large geodetic survey is being started in South Africa under the energetic Sir David Gill; and many of us now living may hope to see this survey extended from the Cape to Cairo; but as yet, from causes well known to you, the work is in

THE ASTROGRAPHIC CHART AND ASTROGRAPHIC METHODS.

AMONG the many achievements of which the Royal Engineers have good reason to be proud there is none which appeals so strongly to an Astronomer as the great Trigonometrical Survey of India; and this, not because of its practical and political significance, but because it forms a large part of the basis of all our exact knowledge of the dimensions of the Universe. To find the distances of the stars we must first know the distance of the earth from the sun which is used as a base line; to find the distance of the earth from the sun we must first know the size of the earth; and for our knowledge of the size and shape of the earth we are largely dependent on the great Trigonometrical Survey of India.

There are not many other surveys as yet of any importance. Europe has, of course, been pretty well surveyed; but the work has been divided among different nationalities using different methods, and there is still much to be done in the way of co-ordination.

Coast surveys are not generally relevant to the purpose named, for they do not as a rule include the measurement of a long arc both astronomically and geodetically, and the size of the earth can only be inferred when we have both these measures. The United States coast survey is indeed extending its operations from both coasts so that they may meet in the interior, and when this work is completed it will form a valuable addition to the material for determining the size of the earth; but unless I am mistaken it is not yet completed. A large geodetic survey is being started in South Africa under the energetic Sir David Gill; and many of us now living may hope to see this survey extended from the Cape to Cairo; but as yet, from causes well known to you, the work is in its infancy. In a word, only measures in Europe and India are as yet available for determining the size of the earth.

We measure the earth at present as the Lilliputians measured Gulliver for a suit of clothes. Finding his bulk too huge for direct measurement, they took the girth of his thumb; and from experiments on their own bodies found the factor by which this should be multiplied to get the circumference of his waist and his other dimensions. India stretches about 20°—about one-eighteenth of the circumference of the earth—in both directions; and, although this means a considerable Empire of which we may well be proud, it is unsatisfactory in determining the earth's circumference to have to multiply by eighteen. We must confess that existing surveys of our globe are distinctly "scrappy."

Until fifty years ago the same might have been said as to our survey of the heavens, and with much less excuse. Terrestrial surveys of remote regions have been difficult and even impossible because of the dangers to life involved; but the heavens have been open to our scrutiny without any attendant risk except perhaps that of catching cold. There is, however, another reason for selection of special regions for survey which is common to both terrestrial and celestial enterprises, viz., some are more immediately *useful* than others. We need not stop to consider the earthly applications of this principle which are obvious enough; but as regards the heavens it may not be so well known that considerations of practical utility had a large share in directing observation. In the old days special attention was paid to the paths of the planets because there was a firm belief in their influence on human affairs. "The stars in their courses fought against Sisera;" and when such allies were liable to appear on one side or another, it was clearly important, even from a strictly military point of view, to be able to follow the evolutions of the celestial army. Coming nearer our own times, it is the needs of sailors rather than of soldiers which have dictated astronomical policy. Our own Royal Observatory at Greenwich was founded explicitly for observations of the moon and fixed stars, in order that sailors might be the better able to determine their longitude at sea; and although the subsequent invention of the chronometer enabled a sailor to carry accurate Greenwich time to sea with him, whence he was enabled to infer his longitude without observing the moon, the policy of observing the moon as often as possible is still maintained at Greenwich; accordingly stars in or near the path of the moon have been much better surveyed than the rest of the heavens.

If I may be pardoned for a small digression, I wonder how long it will be before the chronometer is in turn superseded by wireless telegraphic signals? If Mr. Marconi's claims are well founded, it should be possible to supply a ship, or a traveller, with Greenwich time during the whole voyage; and there should be no longer any difficulty at all in finding longitudes. Again we have been told that the chief difficulty in getting good forecasts for the British Isles is that our weather comes from the Atlantic where there is no observing station. But it seems possible that any ship crossing the ocean is a potential observing station henceforth, and our forecasts ought to become worth something. But how soon will it be? Sometimes a long interval elapses between actual discovery and the utilization of it. In his life of Captain Cook, our present Hydrographer remarks that Captain Cook did not take with him on his first voyage round the world a single chronometer, although the invention had been made some time previously; he preferred apparently to trust to the old method of observing the moon and took with him an astronomer for the purpose. And so although Mr. Marconi seems to have already rendered practical a simple means of determining longitudes, it may be many years before we see it actually employed.

But to return to surveys of the sky—the first step towards a complete survey of the sky (beyond the few thousand bright stars) was made about fifty years ago by a celebrated German called Argelander. This was before photography of the stars had been rendered feasible, and his methods were most laborious, as we shall presently illustrate; but he and his hardworking assistants completed the work for the Northern hemisphere. They made a series of maps which would fit on to a celestial globe about seven feet in diameter—not a very large scale when we consider that our 1-mile to 1-inch maps correspond to a globe over 200 yards in diameter. Still Argelander's was a most useful work, and it has recently been extended to the Southern hemisphere by photography.

The project I have to speak of to-night is that of making by photography the equivalent of a celestial globe 50 feet in diameter, or what may be called on the analogy of terrestrial maps 14 miles to the inch. This is a notable advance on anything done before, though it still falls short of what we may hope to do in the future, even if we aim no higher than the counterpart of the terrestrial mile-to-an-inch map.

Before detailing the historical circumstances which led up to this project, I should like to say a word or two about the way in which astronomical photographs are taken. It is not necessary in these days to explain to anyone what a camera is. The camera of the astronomer, however, differs from the ordinary camera in practically two essential respects. First, the focal length is generally a good deal longer. If, for instance, I want to photograph an eclipse of the sun, with an ordinary camera of (say) one foot focus, I should get a picture in which the obscuring moon would be a black disc of only one-tenth of an inch in diameter, and round the edge would be seen, but on a very small scale, the beautiful corona which appears only on the occasion of a total eclipse. It is preferable to have a much larger photograph.

On the screen is shown* the long camera of 40 feet focus used by Mr. Michie Smith, the Government Astronomer at Madras, in photographing the eclipse of January, 1898, an occasion when I was also in India, photographing with another apparatus close by. On that occasion we were very kindly treated by the Royal Engineers who had charge of us—Major Burrard, Capt. Crosthwaite, and others. They cleared about a square mile of ground for us; they set up gorgeous tents, perhaps not equal to those used at the Durbar, but still very comfortable; they borrowed an elephant from a local Rajah for our use; and I believe they would have got a tiger for us to shoot, but they explained, rather apologetically, that the tigers were strictly preserved by "the Politicals." Mr. Michie Smith's camera is fitted at the top with apparatus for reflecting the sun into it. The camera is not pointed directly at the sun, but a mirror reflects a light down the camera to the dark room at the bottom, where the photograph is taken. The mirror is moved by clockwork, and that brings me to the second point wherein the camera of the astronomer differs from that ordinarily used. Either the camera itself must be pointed to the stars and moved by clockwork to follow their apparent movement, or a mirror must be moved so as to reflect the light constantly in one direction; otherwise the motion of the earth would carry the celestial body across the sky and we should get a confused picture. On the screen is a photograph* of the region of the heavens near the North Pole, taken without clockwork. You see the Pole star has made a long streak of light, and similarly other stars at different distances from the centre have made such streaks. There are a variety of instruments of the reflecting type for counteracting this motion. Some are called

* Not reproduced.—Ed.

heliostats or siderostats; and another, which is called a coelostat, is particularly useful. On the other hand you may make the camera move itself as in the ordinary equatorial telescope, used for visual work. Indeed the camera is usually attached to a visual telescope through which the operator looks in order to keep one particular star steadily in view; for the clockwork is never quite perfect and a little final control by hand or from a pendulum is necessary.

Comet of 1882.

And now I will say a word or two about how the particular project of making this map arose. The train of circumstances began with the appearance of the comet of 1882, which was the last great comet anyone in the Northern Hemisphere had a chance to see, although one appeared recently in the Southern Hemisphere. (The one which appeared the other day did not count, for if any of you did see it you must have been disappointed.) The comet of 1882 was a very big one and stretched right across the sky. It was so fascinating an object that photographers tried to obtain pictures of it; but having only ordinary cameras, which are swept round by the earth in its daily motion, they could not get any result of value. The Director of the Cape Observatory, Sir David Gill, invited Mr. Allis to strap his camera to the equatorial of the Observatory, which had clockwork for counteracting the earth's motion; and some beautiful pictures were then obtained (*Plate* I.).

But it is not the central feature of these pictures, the comet itself, which immediately concerns us. A quite unexpected result was the appearance of a vast number of stars on the plate as well, and Sir David Gill immediately thought, why not make maps of the heavens by photography? It was not entirely a new idea, but it was certainly new that so many stars could be obtained with such an exposure; and a great deal of this was due to the invention of the "dry plate," which was a great improvement on "wet plate" photography.

Discovery of Neptune.

In order to show you what a great advance this was on the old visual method I will show on the screen* the way in which star maps

* Not reproduced.—Ed.

had to be made before photography was used; how, for instance, Argelander observed the 200,000 stars to make his map which covered a globe seven feet in diameter; and how the map was made by the help of which the planet Neptune was discovered. About half-a-century ago the planet Neptune was discovered by mathematical analysis. Two mathematicians had satisfied themselves that a planet existed in a certain region of the heavens; but, since any one of about fifty stars in that region might be a planet, a star map of the region was necessary in order to identify the planet. This was the way in which the map had to be made (*Plate* II.).

The little aperture represents about as much of the region as can be seen at once through a good visual telescope; and, owing to the motion of the earth, if the telescope is kept fixed the stars will appear to travel across the small field of view. And so gradually one after another comes in, crosses this central wire and disappears on the other side. The moment of crossing the wire is noted and also the height at which it crosses. These two observations give us the position of the stars in the sky. In about twenty minutes the small aperture will have traversed the region represented on the screen, and we should get perhaps half-a-dozen stars recorded; and then we must begin again higher up or lower down. You can see how slow the old method was. By photography it would be but a matter of a few seconds to do all this with one exposure, and you can get some notion of the advance which has been rendered possible in making star maps.

Sir David Gill, as I have said, was struck with the idea of making a map of the stars by photography, and a similar idea had struck the Brothers Henry, of Paris, who were slowly and laboriously making a large scale map of a small portion of the heavens by old-fashioned methods and, having almost come to a standstill at one portion thickly studded with stars, caught eagerly at the promises suggested by these comet pictures and tried whether photography would help them. The result was a very great success, though it was not attained without immense labour, skill, and the courageous support of Admiral Mouchez, the Director of the Paris Observatory, who made light of administrative difficulties. But when once satisfactory results were obtained, they were so completely successful that it seemed imperative to complete, not only the original project of the Brothers Henry, which included only a small portion of the heavens, but a map of the whole sky on the same scale.

International Conference, 1887.

For this, however, co-operation was necessary. To cover the whole sky with plates of the kind they were taking would require a total of 11,000 plates; and it was beyond the power of a single observatory to obtain these in a reasonable time. Accordingly Admiral Mouchez and Sir David Gill called together an International Conference at Paris in April, 1887, which was attended by eminent astronomers from different countries as follows:—France twenty, British Empire eight, Germany six, Russia three, Holland three, U.S. America three, Austria two, Sweden two, Denmark two, Belgium one, Italy one, Spain one, Switzerland one, Portugal one, Brazil one, Argentine Rep. one. Many of the decisions of this Conference, arrived at after hard work and earnest discussion, and decisions which have had an important effect not only on this particular work but on the progress of astronomy generally, we have not the time to consider to-night. It must here be briefly stated that 18 observatories were chosen to share the work; that they were all to use a standard pattern of telescope, similar to that which the brothers Henry had adopted (giving a scale of one minute of arc to a millimètre; or, in the terms already made use of, a celestial globe of 25 feet in diameter); and that the sky was to be covered four times over, twice with plates of long exposure (originally defined as 20 minutes, subsequently extended to 40 minutes, and ultimately in some cases to an hour) and twice with plates of short exposure; thus giving about 1,200 plates of each exposure to each participating observatory.

Our National Observatory at Oxford and the Observatories at Sydney, Cape of Good Hope, and Melbourne were among those selected to take part in the work. Since the beginning of the project one or two of the Observatories have dropped out and Perth, in West Australia, has come in, so that altogether we are bearing a worthy share in the project. To give an idea of the size of the map (and I may say sheets of the map have already been published) it may be stated that when completed it will form a pile of paper 30 feet high, weighing about two tons. The question of storage will be a serious matter. With regard to the actual taking of the photographs there is not much to be said. Everyone in these days knows what taking a photograph means, and the taking of these particular photographs does not differ very much from the taking of others.

I think, however, it may be of interest if we turn to some of the results which we expect will accrue from this work, and which are already beginning to appear. In the first place one of the advantages of the survey is that we are to some extent enabled to detect new objects, new stars, or new planets. We shall also be able to compare the sky of the future with that of the present, and to see whether any new objects have appeared.

Discovery of Nova Persei.

You may remember that in May, 1901, a new star appeared in the constellation Perseus, and I will show you a photograph of the region with the new star in the centre, taken very shortly after its appearance. This star suddenly blazed out to beyond the first magnitude and went by the name of Nova Persei. The new star was similar to those that have appeared at different times, and obviously originated from a celestial convulsion of some kind. We should not have known the date of its appearance so exactly (for it might have been in the sky some time before it was noticed) had it not been for a photograph taken by Mr. Stanley Williams, only twenty-four hours before it was first noticed. This photograph shows many more stars than the latest previous one, but Nova Persei is not there; we are thus enabled to fix the date of its appearance with considerable accuracy.

The new star has since become so interesting that I may be pardoned for a slight digression in order to describe what has happened to it in the months which have elapsed since it was discovered. It became less bright, and was not conspicuous to the eye, although it could easily be seen through a small telescope. Some months after its birth photographs taken with powerful reflecting telescopes showed a wonderful nebulous structure all round it; but what was more wonderful still, this structure was seen to be undergoing rapid changes.

Plate III. contains reproductions of photographs taken with the powerful reflecting telescope at the Yerkes Observatory by Mr. G. W. Ritchey; and, by noting carefully the position of the nebulosity with respect to the stars, you will see how rapidly it is expanding in all directions. It was at first thought that these were the actual products of the explosion, scattered outwards like the fragments of a shell; but it was soon found from independent evidence of the distance of the star, which enabled the actual velocity of the expansion to be calculated, that this velocity must be far greater than any at which actual matter has hitherto been known to travel. We have experience of stars moving *hundreds* of miles per second, but the velocity of the expansion of the Nova Persei nebula was found to be more nearly *hundreds of thousands* of miles per second, a velocity comparable with light itself. And when this resemblance of magnitude was once noticed, it was a step soon taken to ask:—May the observed motion be indeed that of *light* and not of *matter?* In other words, if the nebula surrounding the star were there all the time, but invisible because unilluminated, it might become illuminated by the tremendous flare-up of the star which occurred in February, 1901, but the illumination would take *time to travel.* Even with the enormous velocity of light it would not reach the vast distances represented by the boundaries shown in the plate for some months after the explosion; and we can see the illumination still travelling outwards, just as we might catch the echoes of a great sound successively from more and more distant hills. There seems little doubt that this is the correct view; and the discovery has led to one of the most amazing methods of detecting the distance of a star that has come within our knowledge recently, for, by measuring the angular distance travelled by light in six months, we are able to determine the distance of the star with great exactness, and hence to infer that the actual explosion occurred some 300 years ago, though the news of it has only just reached us. This single instance will suffice to illustrate the importance of "new" objects, and it will be clear also that we ought to pick up any strange objects as soon as possible.

Hence several methods have already been suggested for rapidly reviewing the stars on a photograph, to see at once whether there is anything strange about any individual. The most recent method is by means of a "Stereocomparator,"—something like a stereoscope—which enables two photographs to be compared at a glance. All the objects which are sensibly in the same place and of the same intensity on both plates do not attract any attention; but it is said that if a star is present on one plate and not on the other the eye feels a distinct shock,—an almost painful sensation—on encountering it. I have not had the advantage of trying the instrument myself, but we learn on good authority that a field of stars may be very rapidly reviewed in this way and peculiar objects detected without the great labour of examining each one specially.

Beside new stars we may find new planets. A planet generally shows itself by leaving a "trail;" instead of a round image such as those shown by the stars there is a short line. Here is a picture* which led to the discovery of the planet Svea, taken by Dr. Max Wolf of Heidelberg, who had no previous suspicion of its existence. In that way many hundreds of small planets have been detected.

But it must be admitted that the detection of new objects is not the principal, not perhaps one of the principal, reasons for the construction of this map. It is rather for the study of well-known and existing objects that we are working; the study of the *distribution* of the stars, and their *motions*. The stars are very irregularly distributed as a glance at any stellar photograph will show. By observing the number of stars in different parts of the heavens we may find out various things about the structure of the Universe. The Milky Way divides our visible Universe of stars approximately into two hemispheres, and the whole structure is in many ways obviously related to the Milky Way; but that is only the beginning; the details are very complex and need careful study.

One point is worthy of attention; before we arrive at any conclusions we must be careful to eliminate instrumental defects. The question naturally asked is:—Does the instrument show the stars equally well in all parts of the plate? If you divide the plate into equal small areas, are we getting as many stars in each one of those small areas? It is impossible to answer the question from a single plate, but by taking a large number of plates and adding together the results in the corresponding areas we get an idea as to the performance of the instrument in this respect. In the result of a count of about 500 Oxford plates we found, for instance, that the totals for one line of small areas were about 80 and 81; but in another row we got something like 70 instead of 80. The instrument was clearly not performing uniformly all over the plate. It was found there was a regular gradation in the number of the stars in different parts of the plate. The stars were densest in a ring round the centre of about 40 mm. radius.

Table for the Oxford Plates.

At the centre	....	87 stars per unit area.
At 20 mm. distance	....	90 ,, ,,
At 40 mm. ,,	....	100 ,, ,,
At 60 mm. ,,	....	77 ,, ,,
At 80 mm. ,,	....	50 ,, ,,

* Not reproduced.

The fault seems common to all instruments of this type, that is, a camera with a single compound lens. An ordinary camera has two compound lenses—four in all—but the *refracting telescope* with which we are taking photographs of the sky has only one compound lens. All the instruments of that kind apparently have the field of exact focus in the shape of a curved surface, so that only a small portion of the plate can be in exact focus, and here the stars are densest; in other parts of the plate some stars are lost from inaccuracy of focus, to the extent of 50 per cent. even on the relatively small areas we are concerned with. Hence we must exercise care in counting; but with due care we may perhaps get interesting results by counting the stars in different portions of the heavens. As an example I may mention an investigation in progress at Oxford which seems to suggest a belt of stars, reminding one somewhat of the discovery made by Major Burrard, R.E., of a chain of subterranean mountains running across India, of which he told us at the Royal Astronomical Society a few months ago. I am glad to hear that this interesting scientific discovery is on the point of being tested for confirmation by pendulum observation.

But the real work of the Astrographic Chart consists in measuring the *positions* of the stars, which will tell us ultimately their *motions*. By settling the accurate position now, and again (say) fifty years hence, we shall get the accurate motions of the stars; and this is practically certain to reveal to us much more than we know of the structure of our stellar system.

As regards the measurement, which is our chief work, we found that the most convenient way of doing it resulted from the use of an artifice adopted for a totally different purpose. When the Conference met, very little was known of what was called the distortion of film by development. The question was whether the process of development really altered the places of the objects taken to any appreciable extent; and as a precaution it was decided to put on the plates a *réseau*, a series of accurately ruled cross-lines, 5 mm. apart. These lines are ruled on a plate coated with metallic silver so as to cut away the silver, and the photographic plate, either before or after exposure to the stars, is placed behind the silver plate and exposed to a faint artificial light for a few seconds. When the plate is developed both the star images and the *réseau* are seen. *Plate* IV. shows one of the plates with the *réseau* lines on it. You will see that there are two or three images of each star. After giving a six-minute exposure, the telescope or camera is very slightly displaced, and another exposure given of three minutes, and finally a third exposure of twenty seconds. This procedure serves several purposes; among others it enables us to distinguish what are stars and what are dust specks. Now though it has been proved that no sensible distortion occurs, and hence the *réseau* has proved unnecessary for its original purpose, the process of measuring consists of locating the position of a star in any *réseau* square, which is quickly done; without the *réseau* it would be a very troublesome matter. The measurement is done by micrometers which vary somewhat in pattern; at Oxford we use the simplest and most rapid. In the eyepiece is an engraved scale from which the distances are read off without any turning of a screw, which of course takes time. In that way we are able to make measurements rapidly, and this is very important considering the magnitude of our work. At Oxford alone 1,180 plates have to be measured and some requisite computations made, and there are about 400 stars on each plate on the average; so that we have about half-a-million star places to deal with. This work has occupied us for more than seven years, and other observatories are taking longer still. We hope to finish it during next year.

As an outcome of the work with regard to the motion of stars I will again give an illustration of the results. Our first business after making measurements is to compare them with observations on a limited number of the brighter stars made at Cambridge about twenty years ago. About 14,000 stars were observed at Cambridge, and we are dealing with ten times the number. One of the first results of the comparison is to make manifest a striking feature of the Cambridge (and other) observations. It has been well known for years that with the transit circle the bright stars are always recorded too soon. This, however, is not the case with photography, and we are able to tell by comparing the results how much too early the transits of the bright stars had been observed. A great many hundreds of stars go to make up the following table:—

If stars of magnitude 10 are observed correctly

then	,,	,,	9 ,,	,,	0.10 secs.	too	early	
	,,	,,	8 ,,	,,	0.16	,,	,,	,,
	,,	,,	7 ,,	,,	0.19	,,	,,	,,
	,,	,,	6 ,,	,,	0.21	,,	,,	,,
	,,	,,	5 ,,	,,	0.23	,,	,,	,,

So far this is only a peculiarity known to exist in the Cambridge observations; it does not tell us anything about the stars themselves. But the other day the question was raised—Are the bright stars systematically moving with regard to the faint stars? This is an important question, as it affects the fundamental construction of the Universe. Some light can be thrown upon it by determining whether the above table would come out the same if we compared the Cambridge observations with plates taken at different dates, between which the bright stars might have changed their places with reference to the faint ones. We had only been at work ten years altogether, and in practice only a five years interval between dates was available; but by comparing the Oxford measures of 1894 and those of 1899 it was found this table *had* changed. There was a difference of one-fiftieth of a second of time between the results of stars of magnitude 6 for the five years. This is a very minute amount, but it is very important. It shows us that there is a definite motion of the bright stars with regard to the faint stars. And it told us something more, though I can scarcely explain the reason fully here. It had been suggested that there was a revolution of the whole system of stars in a sort of whirlpool, and this would not only have been an interesting fact from a scientific point of view, but it would have had the practical result of affecting the length of the year, although very slightly. But the change of one-fiftieth of a second just found was in the wrong direction to accord with this view; and although we have still to find out the nature of the systematic "drift" of bright stars, it can scarcely be due to any whirlpool effect.

This will show that the work on the Chart is already beginning to furnish results of interest. Others, of which we cannot foresee the nature, will undoubtedly follow; in scientific work it is always the unexpected which happens, and some of the best work is done with no particular expectations at all.

Returning to the project itself, I would, in conclusion, venture to express the hope that the work, while ambitious enough in scope, is not too ambitious. In its details, the scheme for the Astrographic Chart hits the happy mean, we may hope, between two possibilities of variation. With shorter focus cameras we might have obtained pictures of larger areas which would show more clearly the broad features of the Universe. In *Plate* V. for instance is an example of Professor Barnard's beautiful pictures of the Milky Way, taken with a portrait lens;

and we see what wonderful bright aggregations of stars, and what equally wonderful black lanes and chasms apparently devoid of stars there are—features of the Universe the explanation of which we have still to find. They would be lost on our Astrographic plates; but these pictures are too crowded with stars and on too small a scale to give much accuracy in measurement. On the other hand by paying too great attention to individual groups of stars we might have made the mistake of adopting too *great* a focal length. Here for instance are two photographs* of a star-cluster taken at the Yerkes Observatory. The first is with a reflecting telescope of about the same focal length as those we are using for the Astrographic Chart; the stars at the centre are confused and crowded so as to render accurate measurement, or even the separation of one from the other, impossible; but by increasing the focal length they can be separated. Mr. Ritchey has lately shown that by a simple device the huge Yerkes telescope, constructed for visual use, can be rendered available for taking photographs. From its construction, only the yellow rays are brought to focus by the object glass; and the violet rays, which are generally made use of for taking photographs, are not capable of forming a well-defined image. Hence Mr. Ritchey determined to photograph with yellow light as can, of course, be done in these days of iso-chromatic plates. He cuts out all the other light by putting a yellow colour screen just in front of the photographic plate, and the results are certainly beautiful. His pictures of the Moon are admittedly the best ever taken and this picture of a star-cluster shows what can be done with the stars, in special cases.

But the chief characteristic of the Astrographic Chart is completeness and comprehensiveness; and special cases are to some extent necessarily sacrificed while it is hoped that a reasonable amount of general accuracy has *not* been sacrificed. We hope that before another twenty years (perhaps another ten years) has elapsed there will be a complete record of the places of some four or five million stars scattered over the sky with strict impartiality—a noble legacy to posterity if it can be realized.

* Not reproduced.—Ed.

PLATE I.

1882.

ATORY, CAPE OF GOOD HOPE.

PROFESSIONAL PAPERS OF THE ROYAL ENGINEERS.

PAPER II., VOL. XXIX. 1903.

CONCRETE AND FERRO-CONCRETE IN ARCHES, ETC.

(*Lectures delivered at the School of Military Engineering, Chatham, on March 5th and 12th,* 1903, *by* E. P. WELLS, ESQ., C.E.).

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CONCRETE AND FERRO-CONCRETE IN ARCHES, ETC.

PART I.

CONCRETE ARCHES.

General Remarks.

The materials used in the construction of arches in this country have been confined in the past to stone, bricks, iron, and steel; and even at the present time it is seldom that any other materials are used, unless it be for arches of very small spans, many engineers and architects, for reasons of extreme caution and safety, being indisposed to use concrete. But I hope to show in the course of this paper that the use of Portland cement concrete is more satisfactory, not only as regards strength, but also as to first cost, an item which, at the present day, has in many instances to be seriously considered. Limited Use in Great Britain.

One of the principal reasons why concrete has not been more often used in this country is the fact that very few engineers have ever seriously experimented with this material; they have only considered it good enough for retaining walls and foundations, and some engineers do not place much faith in it, even for the latter work; and where it is used it is very often made abnormally strong for fear of accidents happening.

I know of cases where the loads on the foundations do not exceed 2 to $2\frac{1}{2}$ tons per square foot, and the concrete is made in the proportion of 4 to 1; whereas this material would carry with perfect safety 100 tons per square foot two months after being made, assuming, of course, that all the materials are good and clean and the Portland cement is of the best quality made and not adulterated.

So long as engineers leave their experimenting to other people, and do not carry out the tests themselves, even to the gauging and making of the concrete into cubes, and the testing also, so long will they lose the advantages of concrete in bridge and other methods of construction.

What I deplore is the want of initiative in all kinds of novel and experimental work in this country. This may be observed in almost every department of the engineering world, and it is not until we are beaten by our Continental and American rivals that we consider it advisable to alter our methods of manufacture.

Use on the Continent.

If we turn to the Continent of Europe, we find that concrete is very largely used, and in some cases wholly so, in the construction of warehouses, bridges, etc., and all kinds of marine work. The principal reason why it has made such headway there is due entirely to the fact that very great care has always been exercised in its making, and it has therefore given complete satisfaction; and, when once adopted, it is very seldom that engineers revert to bricks and stone, unless in a district where stone costs much less than either brickwork or concrete.

Advantages of Concrete.

There is a homogeneity about concrete, when properly made, that is not obtained where bricks or stone are used; and if any one of you present have had to pull down structures built of either stone, brick, or concrete, I think you will agree with me that concrete is not the material you would prefer. My experience is that good concrete well rammed is a most difficult material to break up when made *en masse;* and, if by any possible chance iron has been used in combination, then it requires dynamite or some other explosive to shatter it.

Comparison of P.C. and Lime Concrete.

Of course, I am referring to concrete made with the best Portland cement and not with lime, though concrete made with lime, which has been thoroughly well slaked, ground up in a mill, and passed through fine sieves so as to eliminate all nodules of lime, and which, therefore, does not contain what is known as "free lime," will, in the course of time, nearly equal concrete made with Portland cement. But lime concrete, unless the same is hydraulic, must be used in a dry soil or place, or it will be next to useless; whereas, as you know, the more moisture that comes in contact with Portland cement concrete the better and stronger it becomes, especially when all the materials used are of a hard nature, such as ballast, gravel, granite, and the very hard limestones and sandstones; but where the soft oolites are used, such as Portland and Bath stone, then freedom from moisture increases the strength, and this is due to the fact that these stones harden so very considerably after being quarried and exposed to the air.

I shall touch upon these points later on, and will now proceed to deal with the construction of concrete arches, first giving you an account of the bridges that have been constructed abroad. I intend to confine myself principally to pivoted arches, which are theoretically and practically the only form of arches that ought to be constructed, and I will show how pivoting at both the springings and centres came to be adopted.

Curve of Equilibrium.

Previous to the adoption of the pivot at both the springing and centre of the arch, it was felt by German engineers that some method should be adopted whereby the curve of equilibrium could be absolutely confined within the centre third. It is well known that in a stone arch it is almost impossible to ascertain where the curve of equilibrium will run, as everything depends on perfect construction, especially in the grouting of the joints, etc.; any defects in grouting up would cause an alteration in the curve of equilibrium, and in all probability might endanger the safety of the structure. It is this difficulty in bedding stones of large area that has compelled engineers to put such a large amount of material in stone arches so as to be on the safe side.

Settlement of Stone Arches.

To show what effect settlement has on a stone arch I would call your attention to the shore span of Waterloo Bridge on the Surrey side, where it was found upon examination that the abutment moved about half an inch, the result being that the joints opened at the keystone, and the whole thrust of the arch passed through a few inches of the extrados; this has caused the voussoirs to spall, and a further movement of half an inch might cause serious mischief to this national monument.

Sheet Lead for Joints.

Some years ago a bridge was constructed in Germany, where mortar joints were dispensed with, and in place thereof sheet lead was used, each piece of lead being made the area of the centre third and fixed on the centre third of the stone. This overcame the difficulty to some extent, as the curve of pressures was compelled to pass through the centre third; but this method of construction was expensive, as the arch stones had to be very carefully dressed to an even thickness, so that all joints were linable throughout, or the thrust in the arch would have been very unevenly distributed. I believe only one bridge on this principle was constructed; but another bridge was built (viz., at Kirchheim) where only lead was used at the springing and centre, and then covering about one-sixth of the area of the arch. It was left to the late President von Leibbrand, the chief engineer to the State of Württemburg, to adopt the method of pivoting in its application to concrete and stone arches; and the adoption of this principle has enabled the State of Württemburg to erect concrete bridges of large spans all over the country, where the use of stone would have been undesirable on account of cost.

Pivoted Bridges.

The first pivoted concrete bridge from the design of the late President von Leibbrand that was constructed in Württemburg was a large one, viz., 164-foot span, and was the pioneer—if I may use the expression—in facilitating erection, reducing the dimensions in the arch, and the use for the first time of the pivot at the springings and centre, which since then has been invariably adopted for concrete arch construction on the Continent, excepting those cases where iron has been built into the concrete and the arches made with fixed springings and practically continuous from abutment to abutment.

I will now, after these few preliminary remarks, proceed to describe the principal concrete bridges that have been erected abroad; and will commence with the "Coulouvrenière Bridge," which spans both branches of the Rhone at Geneva, and which I have no doubt some of you present have seen.

Coulouvrenière Bridge, Geneva.

Fig. 1, *Plate* VIII.

Before a concrete bridge was finally decided upon the town councillors of Geneva had many propositions placed before them, viz., a steel bridge, two designs for a masonry bridge, and two designs for a bridge composed of "Beton Armé," one on the Hennebique and the other on the Monier system. All of these were rejected, and it was not until the matter of design was taken in hand by the technical office of the waterworks and hydraulic pressure mains of the town of Geneva that a satisfactory design was at last decided upon, a concrete bridge being the outcome of many months' deliberation.

This bridge was commenced on the 1st of April, 1895, and completed on February 1st, 1896, so as to allow the narrow gauge locomotives to run over the bridge; it was opened for foot and vehicular traffic on April 22nd of the same year. The actual working time in which the bridge was constructed was nine months, a loss of time of a little over three months being caused by a very severe winter and by heavy floods in the River Arve, which backed up the waters of the Rhone and so prevented any work being carried on; in fact the floods were so bad that, to save time, it was decided to construct the arch over the left bank of the Rhone before the abutment was built; this was done, and many of the foundation piles for the abutment were driven from the completed arch, a method of construction which I think is unique in bridge building.

The two large arches of this bridge have spans of 131 feet 3 inches, with a rise of 17 feet 6 inches, or a ratio of rise to span of 1 to $7\frac{1}{2}$. The arches are 3 feet $3\frac{3}{8}$ inches thick at both springings and centre, and about 4 feet 6 inches at the haunches, and are pivoted. The two smaller arches are respectively 35 feet 5 inches and 39 feet $4\frac{1}{2}$ inches, but are not pivoted, being elliptical in form. The breadth of the river which the bridge crosses is 351 feet, and the total length over the abutments is 492 feet 3 inches. The width of the bridge between the parapets is 61 feet 4 inches, the footways being 12 feet 6 inches each, with a carriageway 36 feet 4 inches between the kerbs.

The space between the outer walls is filled up with nine spandril walls, all of concrete, and about 6-feet 7-inch centres, the walls being about 2 feet thick. To strengthen these spandril walls two horizontal tables are formed, 12 inches thick, and long tie bolts are built in at regular distances. These bolts add very considerably to the strength of the structure, and absolutely prevent any bulging of the outer spandril walls. The top table forming the roadway is made of concrete arches not less than 18 inches thick at the centre.

The arch ring is artificial, and was constructed as follows:—The outer shuttering was made with raised panels which, when the concrete voussoirs were built, formed sunk panels; into these panels were afterwards fixed slabs of rock-faced Jurassic limestone. This method was employed to save the large expense of stone voussoirs and also time in erection, as the fixing of the stones would have taken many weeks before the concreting could have been commenced. Any one looking at the bridge would not imagine that the so-called arch stone voussoirs were only slabs, unless the same was pointed out to him.

The outer spandril walls are faced with stone, the cornice is also of stone, and the parapet is made of rose-coloured granite, as are the columns, portions of which are polished. The concrete forming the two large spans is made out of $4\frac{1}{2}$ to 1 Portland cement concrete by weight, and the mass was formed as follows:—Eight parts of broken stone to 5 parts of sand, which had been passed through a 3-millimètre mesh sieve (or, say, $\frac{1}{8}$ of an inch), the balance of Portland cement making the proportion $4\frac{1}{2}$ to 1. The amount of water used varied according to the state of the weather, but only sufficient was employed to make the mass plastic and allow the water to rise to the surface by means of heavy ramming.

The strength of the concrete as tested by crushing machines, the cubes being made from the concrete as put into the arch, varied between 230 and 300 tons per square foot 28 days after being made; so that within one month, supposing that the bridge could have been finished and the centres struck, the arch was sufficiently strong to carry the heaviest traffic that could be passed over it, and this with a factor of safety of from 10 to 1 to 15 to 1. The number of voussoirs forming each arch was 42, and they were about 3 feet 3 inches wide, the depths varying between 3 feet $3\frac{3}{8}$ inches and 4 feet 6 inches; in my opinion the number might have been halved, and so fewer joints required in the concrete.

The spandril walls, tables, and other portions of the concrete work were composed of 6, 7, and 8 to 1 Portland cement concrete.

The centres throughout were made of wood; and sand boxes were used, each one carrying about 28 tons and made of turned oak (8 inches diameter), fitting into a cylinder made of wrought iron ($\frac{1}{4}$ inch thick). Very fine sand was obtained, the same being thoroughly well baked before being used, and the top of the cylinder was covered over with a waterproof composition so as to prevent water from finding its way into the sand. Four plugs to each sand box were used, so as to regulate the flow of sand when striking the centres.

The large arch over the right bank of the Rhone settled 24 millimètres when the centres were struck, and the arch over the left bank 31 millimètres, or $\frac{31}{32}$ of an inch and $1\frac{1}{4}$ inches respectively. The left arch was the one constructed before the abutment was built, and there is no doubt that this excess of settlement over the right arch was due to the fact that the abutment was green, the concrete used for the abutments being made with hydraulic limes. The maximum settlement in the piers and abutments, seven months after the centres were struck, did not amount to more than 5 millimètres, or $\frac{3}{16}$ of an inch.

After the bridge was completed it was subjected to the following severe tests which, in my opinion, are sufficient, without any other tests whatever, to justify the use of concrete in bridge construction, not only for vehicular traffic but also for railway bridges where the traffic is of the heaviest description.

On the 15th February, 1896, three months after the last voussoir of concrete was finished in the left arch and sixteen days after the centres were struck, a couple of locomotives, weighing 60 tons, were run over the narrow gauge railway without the bridge showing any signs of deflection whatever.

On March 23rd and 24th a rather severe test was made, viz. loading the structure with a layer of gravel weighing 3 cwt. per square foot of footway and roadway surface, a weight which under normal conditions could not possibly be occasioned; even this heavy loading did not cause any appreciable deflection. But, to make assurance doubly sure, it was decided to send over the bridge two locomotives which were made for the Jura, Simplon, and St. Gothard Railway and which were exhibited at the National Exhibition then being held in Geneva; these locomotives weighed 151 tons, and not the slightest sign of failure could be detected in any part of the structure; the measured deflection in the centre only amounted to 5 millimètres, or $\frac{3}{16}$ of an inch, and it is difficult to say whether this deflection was entirely due to the rolling load passing over the bridge, or partly due to a fall in temperature; but, under any circumstances, the deflection was very small and is not likely to happen again, especially under the normal conditions of live loads that pass over road bridges.

The pivots for this bridge were made in the same manner as those for the Munderkingen Bridge, which I will describe later on.

Expansion joints were made in all the spandril walls over the pivots at the springing, and also at the centre; but when the Engineers were fixing the cornice they evidently forgot about the expansion joints, the result being that in the following winter the cornice was broken right through and large spalls of the stone were broken off by the tremendous strain that must have been put upon it; the difference in level at the centre of the span between summer and winter temperatures amounts to as much as $1\frac{1}{2}$ inches, and this would cause a large movement in the road surface at the abutments, due to the fact of the rise being 1 to $7\frac{1}{2}$ of the span.

This bridge cost only £68,000, or at the rate of £137 per lineal foot, or £2 4s. per square foot super of the roadway and footways; and considering its size, the amount of ornamentation, etc., the cost is very low indeed.

The quantity of materials used in its construction were as follows:—20,274 cubic yards of lime and Portland cement concrete and 42,372 cubic feet of cut and dressed stone. The hydraulic lime in the foundations amounted to 1,570 tons, and Portland cement for arches, etc., to 3,400 tons; whilst the amount of timber required for scaffolding and centres, etc., amounted to 91,806 cubic feet.

The total cost per cubic yard, including the cost of centering and scaffolding, works out at £3 2s. 3d., which is a very reasonable figure indeed. In this country I doubt very much whether the same class of work could be done for less than £5 per cubic yard as an overhead price.

Since this bridge was completed I have been twice down in the interior at the springing of the arches, etc., and have also examined it thoroughly; and, beyond the cracking of the cornice, I could not detect any fault or failure in any part of the structure.

Next to the Alexander III. Bridge, at Paris, I consider the Coulouvrenière to be the handsomest bridge in Europe.

Munderkingen Bridge, Württemburg.

Fig. 2, *Plate* VIII., *and Plate* I.

The Munderkingen Bridge was erected across the Danube at Munderkingen in Württemburg in the year 1893. This bridge is the first one where pivots were used either in the construction of a stone or concrete bridge.

The clear span of the bridge is 164 feet and $\frac{3}{4}$ of an inch with a rise of 16 feet 5 inches, or in the proportion of 1 to 10.

The thickness of the arch at the centre is 3·28 feet, at the springing 3·61 feet, and at the haunches 4·26 feet.

In determining the curve of the intrados of the arch, it was found necessary to ascertain the curve of equilibrium, which was made the mean of the curve for dead load and the curve with a live load of about 82 lbs. per square foot of footway and roadway area.

The curve being ascertained it was then made the neutral axis of the arch, the consequence being that instead of the intrados for the whole arch being a segment of a circle it is a compound curve. The half of the span on the down gradient works out as a segmental curve and was struck to a radius of 213·3 feet; whereas the right-hand half was struck for two-thirds of its length towards the springing from the crown to a radius of 229·7 feet, and for the remainder of its length to a radius of 150·9 feet.

Where possible, it is ever advisable to make the intrados a compound curve, so as to take off the appearance of flatness that is always apparent in a segmental curve where the same is seen in perspective.

The stresses in this bridge came out much higher than anticipated, owing to settlement of the centres and a slight giving of the abutments. The calculated stresses at the crown were 32·33 tons per square foot, at the springing of the left-hand arch $32\frac{1}{2}$ tons per square foot, and for the right-hand arch 33 tons; but, in consequence of the settlement, the stresses in the haunches were materially increased, so much so that in the left-hand arch the compression amounted to $34\frac{3}{4}$ tons and in the right-hand arch to 36 tons per square foot.

During the construction of the arch, owing to insufficient support, the centres at one springing settled nearly $\frac{1}{2}$ an inch, which was due to the piles not being driven sufficiently deep.

This settlement caused the faces of the steel pivots to shift from their bearings, and it was found necessary to cut out the pivots, readjust the same, and concrete them in again to their proper positions; they were at the same time screwed and wedged up into place, and there was no further trouble afterwards.

From the commencement of concreting the arch until its final completion a period of three weeks elapsed; and within ten days after the closing in of the final voussoirs the centres were lowered $1\frac{3}{16}$ inches to counteract any swelling on the centering, as water was used freely so as to keep the concrete wet, the weather at the time being very hot.

After a lapse of twenty-eight days, the centering was finally struck, when the set at the crown amounted to 3 inches; after a period of five months, when the range of temperature was 40° Fahr., the final set amounted to $5\frac{3}{4}$ inches; and, as the set or variation at the centre due to a range of temperature of 100° Fahr. would only amount to 2 inches, it follows that the abutments must have taken some time to come to a period of rest.

The left-hand abutment extended in a horizontal direction $\frac{1}{4}$ of an inch; the right-hand abutment extended $\frac{1}{8}$ of an inch and also sank $\frac{1}{16}$ of an inch. Had these defects arisen in a non-pivoted bridge there is no doubt that something serious would have happened, as the whole thrust of the arch at the centre would have had to be taken up at the extrados of the keystone which would have undoubtedly crushed.

The pivots on the bearing boxes are not continuous, but are twelve in number, being 1 foot 8 inches wide by 2 feet 8 inches deep, so that the actual bearing of the boxes is 20 lineal feet, as against 24 feet 7 inches, the width of the arch; therefore the pressure on the concrete at the back of the boxes was increased to over 55 tons per square foot. In the case of the Coulouvrenière Bridge this pressure does not, however, exceed 33 tons per square foot.

The bearing boxes which are built in flush with the radial face of the springing voussoirs are about 2 feet 8 inches by 1 foot 8 inches, and are made of three rolled joists riveted to wrought-iron plates. In the centre of the outside plate a flat steel rail, about $2\frac{3}{4}$ inches wide by 1 inch thick, is riveted, one on each box, and these rails are very carefully machined to a rolling curve of about 6 inches.

Great care was exercised when fixing the boxes that there should be a perfectly true bearing both longitudinally and transversely, as the whole thrust of the arch has to be transmitted through these pivots or joints. The pressure per square inch on the pivots or joints on this bridge amounted to 4·85 tons, and in the case of the Coulouvrenière Bridge the pressure was only about 3 tons per square inch, which gives a very high factor of safety, especially for the latter bridge.

The Munderkingen Bridge is constructed in a similar manner to the Coulouvreniere Bridge, viz., with internal and external spandril walls, and horizontal intermediate tables to strengthen the spandril walls; but very little stone was used in its formation, except in the spandril face, which was made of random Jurassic limestone. The cornice, etc., was made of concrete and the various parts of the work were tinted so as to improve its general appearance. The work was tinted as follows:—The projecting voussoirs were made to imitate red sandstone, as were also the keystones, imposts, and the string courses to the abutments and small side spans on either bank of the river. The columns, and likewise the parapet walls over the side openings, were tinted a pale green, the projecting panels on them being tooled so as to represent stone; the projecting voussoirs of the arch ring were tooled and rock faced.

The use of colour in cement work cannot be recommended in large towns where there is a considerable amount of sulphuric anhydride in the atmosphere; but in country districts, where the air is pure, the use of coloured concrete may be freely indulged in, as it lends to the artistic improvement of the structure.

This bridge was opened for traffic on the 16th of November, 1893, and the period occupied in its construction was about seven months.

The cost of the bridge and abutments amounted to nearly £3,600, or about 13s. 6d. per square foot of road and footway surface.

The approaches to the bridge cost approximately £1,000, so that the total cost only amounted to about £4,600, which is a very low figure indeed.

KIRCHHEIM BRIDGE, WÜRTTEMBURG.

Fig. 3, *Plate* VIII., *and Plate* II.

This is a four-span concrete bridge which was erected over the Neckar at Kirchheim in the year 1897. In its construction several novel features were introduced, viz., the use of lead at the springings and centres, and also the substitution of screw jacks for striking the centres in place of folding wedges or sand boxes, the former method being now generally adopted in Württemburg for the construction of all arched bridges.

The width of the River Neckar which is spanned is 361 feet; the total width is 591 feet, and includes 230 feet of foreshore, which is flooded in the spring and early summer.

The maximum rise of the water at this bridge above the mean or normal summer level occurred in 1824, when the flood waters rose over 19 feet 8 inches; and in constructing this bridge all temporary works had to be removed before the flood waters rose, otherwise serious damage would have resulted, in consequence of the large masses of ice and logs of timber that are brought down by the river when in flood.

The bridge is constructed of four spans of 124 feet 8 inches, with a rise at the centre of 18 feet, or in the ratio of 1 to 6·93.

The thickness of the piers at the springing level is only 7 feet 6 inches, and the sides are struck to a radius of 14½ metres or 47 feet 6 inches.

The thickness of the arch at the crown is only 2 feet 8½ inches, gradually increasing in thickness towards the springing where it amounts to 2 feet 11½ inches. The composition of the concrete throughout the arch was in the proportion of 7½ to 1, which appears to be the strength generally adopted in Württemburg for the construction of arches made of concrete; for the spandril walls, tables, etc., the proportion was 9 to 1; in the foundations for the piers, which were put in under water, the proportion was 4 to 1, as a lot of the cement would, no doubt, be washed away owing to the concrete being lowered through the water.

The whole of the centering for this bridge had to be erected after the floods had ceased and removed before the next season; it was this enforced speed in construction that originated the use of screw jacks, as by this means the centres can be adjusted rapidly to the proper curvature and levels and can also be lowered or raised if required during the process of turning the arch. The maximum weight carried by any screw jack did not exceed 25 tons, and in all cases the jacks were tested to double the working load under hydraulic pressure and were easily moved by hand.

After the centres were fixed they were covered over with wood laggings; the shuttering for the arch voussoirs was shaped so as to give the appearance of stone voussoirs, and after the shuttering was removed the voussoirs were tooled and the raised panels rock faced.

The arches were divided up into spaces longitudinally of about 5 feet, and the concrete voussoirs were made in this width by the full breadth of the arch. All four arches were concreted simultaneously, and from start to finish were completed in twelve days, which, I believe, is the quickest piece of work ever done so far in arch construction.

The lead joints in the centres and also at the springings were made of the best hammered lead, 6 inches wide for the centre and 7 inches wide for the springings, and were bedded in stone, the same being recessed to receive the lead which was about $\frac{3}{4}$ of an inch in thickness.

During the process of turning the arches the centering at the crown settled on an average 2 inches; I put this down entirely to the soft nature of the wood used, as I found from observation at the time of the construction of the concrete bridge at Tübingen that a similar fault occurred there.

Eight weeks after the arches were turned there was a further set of $\frac{5}{8}$ of an inch, due to the superimposing of the spandril walls and tables and the concrete arches supporting the roadway and footways. After the centres were removed there was a further set of $1\frac{3}{16}$ inches, which I attribute entirely to the compression of the lead joints. I examined this bridge thoroughly in September, 1900, and failed to find any fault whatever, there being no signs of fracture in any part of the arches or piers.

The concrete on the face was made of various coloured cements, similar to the system adopted at Munderkingen ; and where it was required for the same to represent stone, the concrete was tooled and rock faced.

The piers were made of concrete throughout, except at normal water level, where three courses of stone were carried all round ; and the cutwaters were faced with stone so as to break up the ice which comes down the river in large quantities in the early spring.

After the shuttering for forming the piers was removed, the surface of the concrete was fine picked so as to represent stone, the joints being **V**-shaped during the process of concreting.

When I visited the bridge three years after construction I could not find that the concrete faces of the piers had in any way been worn by the action of the current, which shows that the concrete was well made in the first instance ; but I may state that the face was made up of about 2-inch thickness of 2 parts of coarse sand to 1 part of Portland cement, and was brought up as the work proceeded ; if the face had been formed of 9 to 1 concrete then I have no doubt that it would have shown signs of wear.

The cost of this bridge, which was 592 feet from outside to outside of abutments, with a width between parapets of 17 feet 7½ inches, was £7,000, or at the rate of 13s. 5d. per square foot of bridge table ; the approaches cost a further sum of £2,250, or a total of £9,250.

This bridge, like the one at Munderkingen, was designed by the late President von Leibbrand who, I regret to say, passed away in 1898.

Eyach Bridge, Hohenzollern.

Plate III.

I now come to a concrete bridge erected at Eyach and designed by Herr Max Leibbrand, Landesbaurāth of Sigmaringen in Hohenzollern.

This bridge has a span of 98 feet 5 inches, with a rise of 9 feet 10 inches or one tenth.

The principal feature about this bridge is that the pivots or joints were made of granite instead of either iron or lead, and no doubt the saving in cost was considerable.

The radii of the rolling curves were $4\frac{1}{8}$ inches and $3\frac{15}{16}$ inches respectively, so that the bearing area per lineal inch was approximately 4 inches when the bridge was loaded, and the pressure per square inch on the granite did not amount to more than 13 cwts. per square inch.

Before granite was adopted for the pivots very exhaustive tests were made, as much as 27 cwts. per square inch being put on the granite without the bearing showing any sign of fracture; and there seems little doubt that, if a granite bearing could be as well made as a turned steel pivot, a pressure of 3 to 4 tons per square inch could be put on it with perfect safety. As these granite joints were sand rubbed the bearing area was in all probability well maintained throughout.

The Eyach Bridge does not, except for the pivots or joints, call for any special description beyond the fact that the footways overhung the arch on either side; to enable this to be done iron entered into the composition, old rails being used for the purpose; this meant an enormous saving in cost, which appears to be of paramount importance where bridge building in country districts is concerned, especially in Germany. If the necessary conditions are obtained, combined with the requisite amount of strength, then I think that first cost should be considered, particularly when it is taken into account that taxation is high and country districts are not able to bear the cost so well as large towns.

The cost of the bridge in question amounted to £900 only; taking the area of the bridge table to the outside of the abutments (viz., 143′·0″ × 12′·6″), this works out at 10s. per square foot as compared with the Coulouvrenière Bridge £2 4s., the Munderkingen 13s. 6d., and the Kirchheim 13s. 5d. It is hardly fair to bring in the Coulouvrenière, as this bridge contained such a large quantity of stonework; but it is useful to show how reasonable the cost per square foot works out in Germany if concrete be used entirely; in this country, however, I should say at least 50 to 75 per cent. would have to be added to these figures, according to the district where the works were carried out.

I shall now deal only with two more concrete bridges erected in Germany, namely the bridge over the River Neckar at Neckarhausen in Hohenzollern (or as it is playfully called in Württemburg "Little Prussia") and the bridge over the Neckar at Tübingen, the university town of Württemburg.

Neckarhausen Bridge, Hohenzollern.

Fig. 1, *Plate* IX., *and Plate* IV.

The Neckarhausen Bridge was designed by Herr Max Leibbrand, of Sigmaringen. It is totally different in design from any of the other bridges I have yet mentioned ; and considering its cost, it is, I think, about the handsomest concrete bridge erected in Germany, especially when we consider that not one cubic foot of stone was used in its construction, the sole material being concrete, except as to the roadway which was formed of macadam and the parapet and hinges or pivots which were of steel and cast iron.

You can hardly form a correct idea of the beauty of the bridge from the drawing or photograph, as the concrete was coloured throughout, and the contrast between the bridge and the surrounding country with its wooded hills and green sloping banks caused the bridge to stand out clear and distinct.

I visited this bridge twice in September, 1900, my last visit being paid when the bridge was completed.

It has a single arch of a clear span of 164 feet and $\frac{3}{4}$ of an inch, with a rise of 14 feet $10\frac{7}{8}$ inches, or a ratio of rise to span of 1 to 11. The arch ring is 2 feet $9\frac{1}{2}$ inches thick at the centre, 2 feet $11\frac{1}{2}$ inches at the springing, and 3 feet $11\frac{1}{8}$ inches at the haunches, and the maximum compression on the concrete does not exceed 26 tons per square foot.

It will be observed that the arch on plan is tapered, being 1 foot 8 inches wider at the springing than at the centre ; this has the effect of reducing the compression on the concrete so that it is fractionally less at the springing than at the centre.

This tapering of the arch has a very pleasing effect as it enables the spandril pillars to be curved.

It will be observed that the longitudinal spandril walls are dispensed with, and spandril columns are substituted ; this means a considerable saving in both material and dead load, and therefore enables the arch ring to be very considerably reduced in thickness.

In the case of the Munderkingen Bridge, which has the same span, but with more rise, the arch ring was on an average 6 inches thicker throughout ; this of course increased the stresses in the arch and also the loads on the foundations.

The pivots for the Neckarhausen Bridge were made somewhat similar to the pivots used for an iron or steel arch bridge, the pins being $3\frac{15}{16}$ inches diameter and the cast-iron brackets or bearings having the grooves bored to the same diameter. These bearings were made in about 2-foot 6-inch lengths, with spaces in between each of about 3 inches, so that you will note that the pins were not continuous. The bases of these bearings were not in any way held to the concrete by bolts built in, but maintained their position entirely by friction between the cast iron and the concrete; when built in position the two bearings were held together with bolts, so that the two beds might be kept radial to the curve, but before the centres were struck these bolts were removed.

The maximum pressure on these pins does not exceed 1 ton per square inch of bearing area, so it will be observed that the factor of safety is very high indeed, and the pins might have been reduced to 2 inches in diameter for the pressure that is upon them.

The concrete in the arch was composed of $7\frac{1}{2}$ to 1 concrete, made in the proportion of 5 stone, $2\frac{1}{2}$ sand and 1 Portland cement, the sand being coarse but very sharp.

The outside of the arch was faced (except at the spandril pillars) with $\frac{3}{8}$-inch spalls of the whitest Jurassic limestone with about one-third of porphyry spalls; these spalls were packed hard against the shuttering and the concrete was then brought up to them.

About four days after the concrete was set the shuttering was removed, and the whole surface cleaned with water and wire brushes; in appearance the finished face looks like scagliola pavement. This plan was adopted for all the outside faces of the spandril pillars, arches, and abutments. The rectangular voussoirs, and also the cornices and edges of the footway paving, were coloured with oxide of iron to represent red sandstone, the oxide of iron being ground up with the cement.

The arches carrying the roadway, where they bear on the abutments, were strengthened with iron rails built into the top; the bottom of the arch, where it bore on the abutment, had iron rods also built in, and then rested on rollers forming a roller path so as to allow for expansion and contraction.

In a case of this kind, where it is found necessary to place the top tables carrying the roadway over the abutment, it is absolutely necessary that iron should be used in its construction; otherwise there would be a collapse, owing to the fact that concrete cannot be relied upon to take up any tension, especially if jolting takes place when a rolling load is passing over the structure.

In this bridge the footways overhang, as in most of the bridges formed of concrete; this, as I previously remarked, is the cheapest method. In this case the footways, as to about 75 per cent. of their breadth, represented the cornice, so that nothing was wasted in material.

The centering was made of wood, supported on piles driven into the bed of the river and also into the foreshore or banks on either side; it was similar in construction to that shown for the Kirchheim Bridge; screw jacks were used for striking the centres.

This arch, during construction and after the striking of the centres, settled 5 inches, soft wood being the principal cause of this set. After the bridge was completed an 8-ton road roller with six horses was kept at work consolidating the macadam; the measured deflection then amounted to $\frac{1}{25}$ of an inch, and this was the final set.

The cost of this bridge with very long approaches on either side amounted to £8,000. I am not in a position to say how the expense was apportioned; but, taking the basis of, say, 13s. 6d. per square foot of bridge table over the abutments, it would amount to £2,950. I shall obtain, if possible, the actual cost to see how it compares with that of other structures.

TÜBINGEN BRIDGE.

Fig. 2, *Plate* IX.

The last concrete bridge constructed in Germany is the bridge over the Neckar at Tübingen, designed by Oberbaurat von Graner. With regard to this structure I had the pleasure of seeing how the Germans do their work, as I was staying at Tübingen during the whole time that one arch and also a portion of the other were turned and other work in connection therewith was executed.

The old bridge, which was of the usual kind constructed in the 15th century, had very little waterway, owing to its enormously thick piers which were carried on oak piles; these piles were as sound when taken out as on the day they were put in; I merely call your attention to this fact, to show that wooden piles can always be safely used in foundations when the air is kept away from them, especially if driven into clay; in this case they were driven into marl.

The new bridge is composed of two spans and a large central pier, built on the island which divides the River Neckar into two branches.

The left-hand arch has a span of 129·23 feet with a rise of 11·71 feet, the ratio of rise to span being 1 to 11·04; for the right-hand arch the span is 118·74 feet with a rise of 10 feet, the ratio being 1 to 11·87. These spans are, so far, the flattest that have ever been built in concrete, the thickness being 2 feet $6\frac{5}{16}$ inches at the crown, 2 feet $7\frac{1}{2}$ inches at the springing, and 3 feet $4\frac{1}{8}$ inches at the haunches; the maximum thrust per square foot on the concrete is $34\frac{1}{2}$ tons, which gives a factor of safety of nearly 8 to 1 and that is more than ample. Spandril walls, about 2 feet thick and 5 feet 4 inches centres, are built in the interior, with top tables 18 inches thick, the outer spandril walls being about 3 feet 6 inches thick. The voussoirs were moulded on the shuttering, and the face work of the same was composed of oolite in the proportion of 2 parts of fine and coarse grit to 1 part of Portland cement, about 4 inches thick; this mixture was well rammed and brought up with the concrete as the work proceeded; after the shuttering was removed the voussoirs were tooled on the flat surfaces, artificial **V**-joints were cut, and the projecting faces rock dressed.

This mixture of oolite and cement makes an excellent artificial stone, and has the advantage that it can be dressed with the same ease as Portland or Bath stone, if too long a time does not elapse after the same is made. I have found, during my experiments extending over the past three years, that a week to ten days after being made is the best time to tool and dress this mixture.

The photograph clearly shows these voussoirs; also the joints and the rock facing. The concrete for both arches throughout was made in voussoirs extending from face to face of the outside spandril walls, and was in the following proportion:—1 part of cement, $2\frac{1}{2}$ parts of sand, 1 part of $\frac{3}{8}$-inch spalls and 4 parts of stone broken to pass through a $1\frac{1}{2}$-inch to 2-inch mesh; only sufficient water was used to thoroughly consolidate the mass by very heavy ramming; in a voussoir 50 feet long by 4 feet 6 inches wide by a depth averaging 3 feet not more than three or four buckets of water oozed through the joints in the shuttering. The Germans use three or four different kinds of rammers or punners, mostly iron; but where concrete is being rammed against existing concrete then special hardwood rammers are used, so that the concrete shall not in any way be injured.

The cement that was employed in the construction of this bridge was remarkably good, being manufactured from natural stone and not, as in this country, from chalk and Medway clay. The stone and spalls were broken up from the best Jurassic limestone obtainable and the sand (from a special quarry) was sharp with fairly large grains; the sand was thoroughly well washed some time before being required so as to enable it to get dry. The stone and spalls were washed twice, the last time just before using. The method of mixing was as follows:—Small V-shaped wheelbarrows, holding the requisite quantity of sand and cement, spalls and stone, were used; a layer of stones was placed in the bottom of a skip, then the cement and sand (which had been mixed by hand), then spalls; and so on until the skip was full, when it was raised and dumped into a concrete mixing machine, where the mixing took place for about two to three minutes, the amount of each charge being about half a cubic metre. The quantity of water used was from $4\frac{1}{2}$ to 5 per cent. by weight, this being found ample owing to the stone and sand used being non-porous.

The concrete was seen during the process of mixing, so that the inspector only passed the same when thoroughly mixed. The concrete when satisfactorily made was then dumped into a trolley and conveyed to the works as rapidly as possible.

The arch that I saw turned took exactly nine days, and this period included the handling and fixing of the stones in which were embedded the pivots or joints. To save repetition, I will deal with the construction of these pivots later on in my paper.

The centres for this bridge were constructed of wood, and screw jacks were used for striking them, the maximum weight on any jack being 26 tons. The settlement of these centres was very considerable, amounting to over 2 inches, and this was due entirely to the soft nature of the wood. I observed, in some cases, that the tie beams, where they bore on the jacks, had compressed $\frac{3}{4}$ of an inch; if oak or pitch pine had been used I do not think that the alteration in the centering would have amounted to $\frac{1}{2}$ an inch. I will now give the deflections of the arch, confining myself to the arch I saw constructed, viz., the one on the right bank. Before concreting the arch on 18th September, 1900, *nil*; on closing right arch on 28th September, 1900, $1\frac{23}{32}$ inches; on 5th November, 1900, $2\frac{5}{32}$ inches; on 6th November, 1900, when the screw jacks were turned through two complete revolutions, $2\frac{25}{32}$ inches; on 13th November, 1900, after the jacks were turned half a revolution, $3\frac{1}{16}$ inches; on 16th November, 1900, with another half a revolution, $3\frac{11}{64}$ inches; and on November 28th, 1900, after all the screw jacks were lowered and the centres struck, $3\frac{7}{32}$ inches; on 30th November, 1900, $3\frac{21}{32}$ inches; on December 20th, 1900, before the cold weather commenced, $4\frac{1}{16}$ inches; on January 7th, 1901, after seven days of intense cold averaging $32\frac{1}{2}^\circ$ of frost Fahr., the maximum deflection took place, viz., $4\frac{9}{32}$ inches; on January 23rd, 1901, after the cold weather had broken up, the arch rose, the deflection being $4\frac{1}{8}$ inches.

The engineers calculated that, owing to the lead seatings at the back of the pivots, there would be a compression of the lead amounting to 1 millimètre for each seating, 6 in all, and that the set of the arch at the crown would be 60 millimètres or $2\frac{3}{8}$ inches; the actual compression was 46 millimètres or $1\frac{26}{32}$ inches, the actual compression taking place in each lead seating being therefore ·733 of a millimètre.

The precise pressure per square inch on the lead amounted to 1,444 lbs. or about $\frac{1}{5}$ of its ultimate crushing strength, which allows a fair factor of safety when it is taken into account that the lead cannot spread beyond a certain point.

This bridge was completed in June, 1901, and thrown open to traffic; had it not been for the severe winter there is no doubt that it could have been finished months sooner, but the intense cold that is experienced in Württemburg during the winter months always puts a stop to any concrete works being carried out.

Before dealing with the construction of concrete arches in detail I take this opportunity of thanking the German engineers, viz., Herren Oberbaurat von Graner, Baurats Reger, and Gugenhan, and Herr F. Probst, Reg. Baumeister, for placing before me all the information in their possession with regard to the construction of concrete bridges, and also Mon. C. Butticaz, the engineer of the Coulouvrenière Bridge at Geneva.

Construction of Concrete Bridges.

Fig. 1, *Plate* V.

I will now proceed to describe the construction of a concrete bridge having a span of 150 feet with a rise of 19 feet; this bridge, the dimensions of which I give, is strong enough to carry the heaviest possible vehicular traffic as also the heaviest railway traffic, and to carry a load of over 3 cwts. per foot super on one half, with the other half unloaded, and all this without the use of iron in its construction; but if iron were used, then the loads could be very materially increased.

The principal reason why these concrete bridges are so safe under unequal loading is due almost entirely to the pivots at the springings and centre, which compel the curve of pressures to pass through the same, the only sensible variation in the curve being at the haunches; even the loading given will not in any case alter the curve so that it passes above or below the middle third. Such being the case, it will be observed that no part of the arch can be in tension; but, should such a thing happen theoretically, the spandril walls, by their great rigidity, will prevent any distortion of the arch; and, if the spandril walls and tables are wired, it would be possible to put a tension of 10 to 15 tons in either the extrados or intrados without the structure collapsing or changing its form.

Another advantage that a concrete arch possesses over a brick or stone arch is its homogeneity, there being an absolute lack of joints which are an element of weakness; as the mortar in the joints is, *e.g.*, in the case of a granite arch, $\frac{1}{20}$ the crushing strength of the stone itself if made of lime and $\frac{1}{4}$ the strength if cement grout is used, then why use a material that is stronger than your weakest part?

In designing a concrete arch, you will find it necessary to start on the assumption that the thinnest part of your arch, viz., at the centre, is approximately $\frac{1}{50}$ of the span; this you must increase at the springing by about 7 per cent., and at the haunches by about $27\frac{1}{2}$ per cent., to allow at this point for varying loads tending to make the curve of pressures rise or fall either below or above the neutral axis, and so to always keep the said curves within the middle third. The Arch.

Having then apportioned the sizes of your spandril walls, or spandril pillars, to the loads that you intend your bridge to carry, also the intermediate tables and tables to carry the vehicular and foot traffic, proceed to ascertain the weight of your structure and find the curve of equilibrium for the dead load only; having ascertained that make it the neutral axis of your arch, and alter the shape of your extrados and intrados by compounding your curves so as to make both equidistant from the neutral axis. Now, as you will readily understand, the normal condition of a concrete bridge is its dead load, and the greatest stresses are set up by the dead load; so I consider that, unless extraordinary loads are to be passed over the bridge, it is not necessary to take into account the live load especially if it is only ordinary or vehicular traffic. But to satisfy yourselves on this point work out the curves for equally distributed loads and also for one half of the arch loaded, and you will find that the curve of equilibrium at the haunches does not vary more than 3 inches either above or below the neutral axis; in the case of a heavy rolling load, it is only when the load is at the centre of the span, or a few feet on either side of it, that the increased stresses at that point in the arch can be accurately calculated; because nearly the whole width of the arch, from the point under the load to the springing, takes up the stresses induced, and the same are reduced to a minimum by the enormous area of arch that they are spread over; the reason why concrete arches are so strong is that the stresses induced by the weights are so well distributed; otherwise there would no doubt be distortion of the arch and great deflection at the centre, whereas in no case, where exhaustive tests have been carried out, has this been proved. Such being the case the cartoon of a 150-feet span as shown will have a maximum compressive stress at the worst point of under 18 tons per square foot; and, if the span be loaded with 2 cwts. per square foot, then the maximum stress will not exceed 24 tons per square foot, and this is very low indeed for concrete which at three months old will stand over 200 tons per square foot in compression.

Under these circumstances it is perfectly permissible to reduce the thickness of your arch until the stresses amount to 36 tons per square foot; but you will then require to ascertain the positions of the curves of equilibrium for dead load, equally distributed live load, and also for one half of the arch loaded, and likewise for the maximum rolling load placed in the centre of the span; you can then make your neutral axis the mean of all the curves.

The effect of this will be that at the haunches, for dead load only, you will slightly increase the compression at the intrados and reduce it correspondingly at the extrados; the curve of the intrados will not require so much compounding but will be more segmental in form, unless you are placing excessive dead loads on the haunches when the curves of pressure will rise and so enable you to compound the curves of the intrados and very materially improve the appearance of the arch.

If it were possible in concrete arch construction to make the arch so that the dead load were equally distributed, then the curve of equilibrium would be a parabola; but the appearance of the arch would suffer, though theoretically you would be correct.

Spandril Walls. *Fig.* 1, *Plate* VI.

Where spandril walls are used it will be found that the most satisfactory dimensions for road bridges are 2 feet thick by 5 feet centre to centre of wall; for a railway bridge the centres should be the distance from centre to centre of the rails, so that the loads are always in the centre of the wall, and in the latter case it is not necessary to make such strong top tables, 9 inches being ample.

The composition of the concrete in the walls is amply strong enough if made in the proportion of 6 to 1 or 7 to 1 ; in Germany they use 9 to 1. Where iron is used in the composition the walls may be reduced to 8 inches in thickness, but the concrete must be increased in strength to 5 to 1. In all cases the spandril walls, and also the concrete filling over the arch beyond the spandril walls at the centre, should be bonded to the arch by means of stone figs, or old iron rods, in the shape of bolts, etc., etc., as by this means you absolutely prevent any separation taking place between the extrados of the arch and the spandril walls, and you have not to depend entirely upon the cementitious nature of the concrete, which is not always to be depended upon unless very great care be taken in roughing the concrete and making the same absolutely clean.

The centres needed for the erection of a concrete arch are similar in every way to those required for a stone or brick arch, with this exception that less strength is wanted, owing to the fact that a concrete arch weighs less. When centres are used for an arch spanning a river where openings are required for purposes of navigation and where the maximum amount of headway and the minimum of construction is wished for, it becomes necessary to use iron or steel ; but under ordinary circumstances wood may be used, and I wish to impress upon you the great importance of using the hardest wood you can obtain, if you want to prevent settlement during the construction of the arch ; pitch pine will answer admirably, but when cills or tie-beams either bear on sand boxes or screw jacks (I prefer the latter), then use well-seasoned oak cleats not less than 3 feet long, and securely bolt the same to the cills or ties to distribute the loads. Centerings.

I do not advise a greater load than 30 tons on either a sand box or screw jack ; but when it is found necessary to carry heavy loads, as in the case of giving large openings for navigating purposes, then special sand boxes of large dimensions must be used. In constructing your timber centering you must pay special attention to all your joints ; in no case tenon your pillars and struts, etc., but make all joints butt and connect the different members together with iron plates and bolts and nuts. I have found that, where timber is tenoned, it is a most difficult matter to obtain an even bearing throughout, and the pressure on the timber where it does bear is often double what it should be, the consequence being that settlement takes place, very often where it is not required.

The use of iron cover plates and bolts, etc., entails an extra expense, but you will be more than compensated by the knowledge that your arch is not going to set abnormally.

After all your centres are fixed and thoroughly braced transversely and horizontally, lay on the top timber laggings, the same having been machine wrought to a uniform thickness so that the concrete intrados will appear smooth. These laggings must not be fixed, but simply laid on; and not jammed tight up one against another, or the water in the concrete will cause them to expand and probably cause rupture of the concrete or an accident to the centering if the concrete does not give.

Assuming that it is required to face the arch with stone voussoirs, then the same must be laid on the laggings; and the joints, instead of being grouted in the usual manner, ought to be made at least ½ an inch, and a cement mortar 1 to 1 (made so dry that only water will come to the surface by ramming) be rammed in; but it is necessary to leave about every fifth joint open until such time as the concrete voussoirs are made and then, when the same are set hard, make the joint as before.

With regard to the keystone at the centre of the span, this must not be put in until the centres are struck. The voussoirs to take the same must be made out of the outside stones in which the pivots are fixed, and then not cemented in but fixed with a poor lime mortar, so that when there is a rise or fall in the arch due to temperature the keystone will not be crushed at either the extrados or intrados.

Shuttering for Concrete Voussoirs. *Fig.* 2, *Plate* VI.

Where it is required to construct the whole arch of concrete, and make imitation stone voussoirs, special shuttering must be made. This can be moulded to any desired form, as you will have noticed from the several bridges that I have already shown on the screen; but great care must be exercised in fixing the shuttering and in well strutting the same, so that in making the concrete voussoirs the ramming does not cause the shuttering to bulge.

In fixing mouldings on the shuttering, there is one point I must impress upon you, viz., that the wood moulds must always be made in two pieces and the joint, instead of being at right angles to the spandril face, must be made to an angle; otherwise, on account of the wood swelling, it would be impossible, without cutting, to remove the wood when the shuttering is taken away. In some cases it is necessary to use three built-up members, the centre piece being wedge shaped; when this is withdrawn the remainder of the wood is easily removed without in any way damaging the arrises. By this means it is possible, if two or more arches are built, to employ the same shuttering and moulds; otherwise fresh moulds must be made for every arch, thus entailing unnecessary outlay where expense is an object.

We will now assume that all is ready for making the concrete voussoirs, for which you have previously prepared your shuttering, which should be made in 15 to 20-foot lengths, these being the most convenient for handling. These shutters can be formed out of 2-inch to $2\frac{1}{2}$-inch wood, strengthened with rails, etc., the surface exposed to the concrete being machine wrought; but it is not essential that they should be of an even thickness, as a slight variation will, when the voussoir is constructed, act as a key. Mark off on the top of your laggings the thickness that you require the concrete voussoirs to be formed; fix your shuttering, the faces in all cases being radial to the curve; and be careful to thoroughly well strut the shuttering, so as to prevent undue distortion in consequence of the weight of concrete. After this is done, cover the surface of the laggings with about 1 inch of 1 part sand to 1 part Portland cement (made dry) and then, as rapidly as possible, commence concreting; the quicker the concrete is put in and well rammed the stronger and better it will be. When once a concrete voussoir is started it must be finished without a break; and sufficient men should be employed, so that, from start to finish, not more than two hours will elapse. When you have finished about three-fourths of the voussoir, the stone figs or iron rods, etc., should be built in for bonding the spandril walls to the extrados of the arch.

If stone figs be used they should not be less than 3 feet long × 12″ × 8″; if iron rods, then not less than $\frac{3}{4}$-inch diameter by 3 feet long, the ends being bent to a right angle so as to prevent them being drawn out. The figs should be about 3-feet centres and irregular in shape, so as to bond well; the iron rods should be about 18-inch centres longitudinally, and 12-inch centres transversely, to the spandril wall.

After the concrete is set, the surface should be covered over with wet sacks, and kept well wetted during the whole time that it is exposed.

This method of construction applies to all the concrete voussoirs, Nos. 2, 4, 6, 8, 10 and 12. Order of fixing Voussoirs. *Fig.* 3, *Plate* VI.

The shuttering may be removed within two days after the voussoir is made; it is then necessary to roughen the radial faces of the voussoirs before the intervening ones are filled in, and to thoroughly clean the same.

I may remark that in the construction of concrete monoliths, as these voussoirs may be called, it is not necessary to use any oil, or composition of oil and soft soap, on the shuttering boards or laggings. Where holes are made in the laggings, by adopting iron dogs or bolts, the best method to follow is to fill the same with plaster of Paris.

It is advisable, when forming the concrete voussoirs, to always place the first voussoir between the points of support of your centres, not over the supports; thus, if any deflection is caused by the weight, it is put into the beam before the remaining voussoirs are made.

In closing in with the voussoirs Nos. 3, 5, 7, 9 and 11 be careful that the faces of the existing concrete voussoirs are thoroughly clean and well roughened; and, as the concrete is brought up, put neat cement grout on the faces of the existing concrete, so that a perfect bond is obtained between the new and the old. When ramming the concrete take care that the existing faces of the voussoirs are not in any way damaged. To prevent this it is advisable to use special hardwood rammers. Lest, by any chance, the faces of the voussoirs previously put in should be honeycombed, be prepared with some 1 to 1 mortar to fill up all interstices previous to the concrete being filled in.

After the completion of the voussoirs Nos. 2 to 12 it becomes necessary to adjust the granite blocks and I shall now describe the method; but I will first inform you of the nature of the labour on the stones and on the pivots.

Pivots. *Fig.* 4, *Plate* VI.

The pivots should be made of the best annealed cast steel, carefully machined all over to uniform thicknesses; the rolling curves should be machined and finished to a dead smooth surface, the rails being forced into the bearing plates by hydraulic pressure; if it be found that the faces of the rails are not parallel with the bedplate, then the back of the same must be re-machined.

The granite bearing stones must be recessed for about 1 to $1\frac{1}{2}$ inches, and the bearing surface bush axed or (which is preferable) sand rubbed, as it is advisable that there should be no inequalities in the stone to prevent a perfect bearing being obtained.

The stones should be made in about 2-feet 6-inch lengths, and the pivots should be about 1 inch less in length. The joints for these stones should be about $\frac{3}{4}$ of an inch, and are not to be made until after the final concrete voussoirs are filled in.

Before fixing the pivots in the stones, sheet lead, about $\frac{1}{8}$ of an inch thick, should be put in the recess in the stones, and the pivots laid in and well hammered with a heavy wooden mall; after which the stones should be fixed in position, and very great care exercised in gauging the distances between the rails so as to ascertain whether the bearing of the two rails is true; any inequality in the position of the stones can be obviated by packings laid on top of the laggings.

Use of Screw Jacks for Fixing Pivots. *Fig.* 5, *Plate* VI.

After all the stones are in their correct positions, it will be necessary to obtain four screw jacks so as to force the pivots as close together as possible and at the same time put a certain amount of compression on the lead seatings; when this is done, force in 2-inch square iron or steel bars between the back of the stones and the concrete voussoirs Nos. 2 and 12, so as to prevent any movement when the screw jacks are taken away.

In Germany they use ¾-inch bolts top and bottom, placed in the joints of the stones; but by this means very little pressure is exerted, and the bolts have to be left in until concreting is finished and afterwards cut out, which is a most difficult and very expensive method of procedure; it is in my opinion one of the principal reasons why there is so much deflection in the arch when the centres are struck, owing to the fact that so little pressure was put on the seatings previous to concreting in.

There is no doubt that concreting exerts a large amount of pressure on the granite blocks, especially when the concrete is made fairly dry and heavy ramming is employed; but the pressure is light as compared to that exerted by four powerful screw jacks. It is not absolutely necessary that all the pivots should be perfectly in line, but it is better from a workmanlike point of view, as the joint on the soffit of the arch can be seen from below.

After all the stones are fixed in position fill in the concrete voussoirs Nos. 1 and 13; the voussoirs in the centre ought to be filled in simultaneously. To prevent the concrete forcing its way into the joints between the granite bearing stones, put in loose pieces of wood which can be removed after the concrete is set. The joints in these bearing stones should not be made for at least five or six days after the final voussoirs are formed, and should then be made as previously described for the voussoirs on the face of the arch; but to allow for any expansion or contraction in the concrete one joint in the centre should not be made until you are prepared to strike your centres.

To ensure that the pivots shall not oxidize I recommend that a special plastic paraffin wax should be poured in, the wax having as high a melting point as possible so that it is not softened by any abnormal rise in temperature; and to ensure that the wax fills the entire space, heat the stones and pivots to a temperature of about 140° Fahr., when the paraffin wax will flow as easily as water. The advantage of using paraffin wax is that it is not acted upon by either acids or alkalies, and it absolutely prevents any air or moisture finding its way to the cast-steel pivots; besides, on account of its plastic nature, it always allows the pivots to act freely.

Upon the completion of the arch all the outside shuttering can be removed, if a concrete face has been made; any tooling or dressing of the concrete can be carried out while the spandril walls are in course of erection.

Spandril Walls and Tables.

Previous to the erection of the spandril walls the surface of the concrete arch, where these walls come, should be thoroughly roughened and scored and the surface washed clean. The shuttering for the spandril walls does not need any description, as all is plain sailing after the arch is completed.

Where it is required to insert an intermediate table to strengthen the spandril walls, the walls below the table, and the table itself, should be made at one operation so as to obtain perfect bonding.

Before proceeding with the construction of the walls cover the surface of the arch with about 1 inch of 1 to 1 Portland cement mortar, and then start concreting. At the same time lay, about 6 inches above the arch and for the whole length of the spandril walls, two 1-inch diameter iron or steel rods, so as to tie the whole wall longitudinally; if great strength is required put in vertical rods about $\frac{3}{4}$ inch diameter by 18 inches centres, and carry the same up to the top tables; these rods will also help to bond the spandril walls to the intermediate tables.

At the intermediate tables it is advisable to lay long 1-inch rods from outer to outer spandril walls so as to bond the whole structure together transversely.

The top tables should have $\frac{1}{2}$-inch rods laid about 1 inch above the bottom (or tension) member by about 6-inch centres; these rods not only tie the work together, but also take up any tension that may be put into the tables by heavy rolling loads passing over the bridge.

When it is required to face the outer spandril walls with stone, I am strongly of opinion that the stones should be held to the concrete by means of $\frac{1}{2}$-inch to $\frac{3}{4}$-inch iron rods, the ends of which are turned down, one end being put into the Lewis hole in the stone and then grouted in, a small groove having been previously cut so that the rod is let in flush with the top bed. By this means you are enabled to use face stones not more than 9 inches thick on bed, with the knowledge that there is no chance of any separation ever taking place between the stone and the concrete. If still greater strength is required, grout nicks ought to be cut in all stones, a flat iron bar (about $2'' \times \frac{3}{16}''$) inserted in the grout nick, and the same then grouted in in the usual manner.

In the connection of the outside stone voussoirs to the concrete, long Lewis bolts may be fixed in the centre of the same, and the ends turned down and built in; but there is not much danger of any separation taking place here, especially if the backs of the stones, and also the sides which are not dressed for joints, are allowed to have rough quarry backs which act as a good key for the concrete.

Striking Centres.

It is not necessary that the whole of the outer spandril walls should be constructed before striking the centres; but, if there is no urgent reason why the centering should be removed, it is better to let the same remain, as it acts as a staging to enable the masons to set the stones on the spandril faces. But within three weeks after the completion of the final concrete voussoirs it is advisable to ease the centres a trifle, so as to allow a moderate amount of pressure to be exerted on the pivots; where screw jacks are used this can be easily done without in any way setting up vibration in the arch such as takes place when folding wedges are used.

Scaffolding.

The scaffolding that is required for a concrete arch can be made very light indeed, as the heaviest weights to be lifted are the granite voussoirs, if the arch ring be faced with stone, and also the granite blocks in which the pivots are bedded; these can be placed in position before any concreting is begun, when the maximum weight to be carried is half a cubic yard of concrete plus the weight of the trolley; when all the tables are finished any weight in reason may be sent over the bridge.

Roadway.

After the centres are finally struck the concrete over the arch, forming the roadway and footway, may be filled in, care being taken to make an expansion joint over the pivots in the centre of the span and also at the springing pivots. In this country a joint $\frac{1}{8}$ of an inch is sufficient at the centre, and the same can be made with soft felt; but at the springings, if the concrete be put in in cold weather, fully $\frac{1}{2}$ inch must be allowed. In forming the roadway, whether of wood paving, granite pitching, asphalte or macadam, the expansion joint may be ignored, though one must be put in on the footways, especially if the same are made of York paving or concrete.

In order to allow the arch to expand the outer spandril faces must not be bonded to the abutments or piers, but be recessed into the same so as to allow perfect freedom of action ; this also applies to the parapet and cornice because, if securely fixed, an accident is bound to happen in winter if the bridge were completed in summer, and *vice versâ*.

You will have noticed that throughout I have shown the extrados of the arch as a curved surface, which is the cheapest form of construction ; but the best method, though more expensive, is to make the extrados in steps from the springing to the end of the spandril walls. The latter method entails more labour in construction ; but this is more than compensated for by the advantage that workmen can easily walk on the arch ; it gives a level surface for the spandril walls to bear on, facilitates the erection of scaffolding and shuttering for the spandril walls, and also saves cutting the shuttering to a curve. This economizes timber where a number of arches are constructed, as there is no waste and the wood can be used several times over. These steps add a little to the weight of the arch, equal to about 3 inches over the whole area ; but, as I have said, the extra cost is more than compensated for in facilitating rapid moving about ; moreover the bonding is able to be made more perfect between the arch and the spandril walls.

Tests of Model Bridge.

Fig. 2, *Plate* V.

I think I have touched upon all the principal points in construction that will enable you to design and erect a concrete bridge, and I will now deal with the tests I applied to a model bridge I constructed of 150 feet span to a scale of ½ inch to the foot.

The arch ring of the model arch had been completed only seven days when the tests were made. The arch ring was composed of 4 to 1 concrete made out of 3 parts of broken Portland stone, 1 part of sand made from the stone and 1 part of Portland cement, all by weight, the amount of added water being over 10 per cent. ; the springings and centres, where the pivots are fixed, were formed of neat cement ; the spandril walls and tables, on account of their small dimensions, were made of 1 to 1 Portland stone sand and Portland cement. The walls were bonded to the arch by means of 3-inch French nails, at about 3-inch centres, inserted during the construction of the arch ; and the walls and tables were bonded together by vertical wires, $\frac{3}{32}$ of an inch in diameter, laid both longitudinally and transversely by about 2-inch centres.

The concrete was made with plenty of water, and no ramming was required, only consolidation with a trowel so as to give a smooth surface. The maximum age of the arch when tested was 14 days for one half and 7 days for the other half; the concrete in the arch crushed at 93 tons per square foot 7 days old, 145 tons per square foot 21 days old, 178 tons 58 days old, $259\frac{1}{4}$ tons 6 months old, and 275 tons per square foot 10 months old.

No load had been placed on the arch before the trials were made so as to bring the piers or pivots to their bearings, and the following deflections at the centre took place :—

With an equally distributed load of 507 lbs. over the whole span (equal to 107 lbs. per square foot) the deflection in the centre was $\frac{24}{1000}$ of an inch; with 336 lbs. in the centre the deflection was $\frac{24}{1000}$ of an inch; and with one half loaded with 507 lbs. (or 214 lbs. per square foot) the deflection was $\frac{26}{1000}$ of an inch. The permanent set amounted to $\frac{14}{1000}$ of an inch, this being no doubt due to the pivots and springing blocks or abutments coming to their bearings. Allowing for the permanent set of $\frac{14}{1000}$ the greatest deflection in the arch due to a central load would be about $\frac{1}{36}$ of an inch or $\frac{1}{2700}$ of the span. There was no permanent alteration in the shape of the arch after the loads were removed.

The weight of each half arch was 113 lbs., so that the maximum load placed on the loaded half was 4·48 times heavier than the half arch itself; whereas in actual practice the live load as a rule does not amount to more than $\frac{1}{5}$ or $\frac{1}{6}$ of the dead load as a maximum.

I show you the equilibrium curve which was induced by this abnormal loading for an arch only 7 days old; the factor of safety for crushing was only 6 to 1; but the tension induced was such that, had not the spandril walls been bonded to the arch and also wired, there is no doubt that the arch would have collapsed. Had the model been made of brick or stone it would undoubtedly have collapsed.

What saved the model from failing were no doubt the pivoting and the wires in the spandril walls and tables and also the perfect bonding of the walls to the arch (which prevented any separation taking place, especially in the unloaded half). I would have no hesitation in loading this model arch with 20 cwts., or over 470 lbs. per square foot.

I think that this experiment clearly shows the great advantage that is to be obtained by the use of iron in the construction of arches and—we will go a point further—the judicious use of iron rods in both the extrados and intrados of the arch itself. I am fairly convinced that by this means it would be perfectly feasible to design and build a concrete arch having a clear span of 300 feet, with a rise of 1 to 9, for the heaviest vehicular and foot traffic, with the certain knowledge that the compression would not exceed 50 tons per square foot, giving a factor of safety of 6 to 1 at the age of twelve months, which is ample. In designing a bridge of this kind I should make use of wires freely both in the spandril pillars and in the table forming the road surface, so as to obtain the maximum amount of strength with the minimum amount of weight; this must be done when bridges of large spans are constructed, as an excessive dead load will produce such stresses that it would collapse under its own dead load.

The reason why I advocate the use of iron in combination with concrete is to enable one to take up any tension; because concrete, where there is no chance of any injury due to tension taking place, will carry safely in compression 100 tons per square foot, especially when it is properly made and with the correct proportions.

As you must all know, where iron and steel are used in combination with Portland cement concrete they are absolutely preserved so long as they remain in contact with the concrete; this is due to the fact that there is no affinity between oxygen and Portland cement.

To show the resistance of concrete due to compression I tested a twelve-month-old cube of concrete made out of 5 parts granite and 1 part cement with the following results:—When loaded with 61 tons per square foot the registered compression was $\frac{1}{2000}$ of an inch for a height of $3\frac{15}{16}$ inches, or 100 millimetres; and when a load of $100\frac{1}{2}$ tons was placed on, the compression was $\frac{6}{1000}$ of an inch. The latter load was left on for nine days, when the cube had compressed a further $\frac{1}{1000}$ of an inch; and it ultimately crushed at 183 tons per square foot, which is a low test for 5 to 1 concrete twelve months old. I put down practically the whole of this compression to the fact that the cube was crushed between polished steel plates and that the faces of the cube, not being so true, simply squeezed until there was a perfect bearing; I have found that when concrete crushes at a high tonnage the faces in contact with the steel are invariably polished.

If this test is worth anything, it shows that one-third the ultimate crushing can be put upon the concrete with safety, and it is possible to put on more than one-half of the ultimate without any signs of failure appearing. The cube, after having 100½ tons per square foot on for the nine days, did not show a single sign of failure at any part, not even on the edges, which were as perfect as when put into the crushing machine. It is a well-known fact that concrete when made in large masses is always very much stronger than when it is made in small cubes, owing to the fact that the water in the large mass takes a much longer time to evaporate than in a small cube and so increases the strength; therefore, when small cubes for testing purposes are made you can rest perfectly well assured that the results you obtain are the minimum. The same rule applies to briquettes, 1½ inch square briquettes always giving better results per square inch than briquettes of 1 square inch in sectional area.

Making Concrete.

I now come to the most important part of this paper, viz., the making of concrete and the proper proportions that ought to be used for different kinds of work.

During the last three years I have experimented largely with Portland stone or oolite, and I have come to the conclusion that for the construction of arches it cannot be beaten. Advantages of Portland Stone.

It weighs less per cubic foot than concrete made from any other stones except Bath stone; it requires less Portland cement; gives greater strength; is much more homogeneous in its nature than concrete made from any other materials; more water can be used without in any way reducing its strength; and it requires less manual labour than any other of the concretes made from flints, gravels, granite, hard limestone, etc., etc.; and, what is of greater importance still, it has an affinity for Portland cement not possessed by the harder limestones. This last is proved by the crushing results, because, when the concrete crushes at over 160 to 170 tons per square foot, the average crushing of the stone itself, every stone in the mass is broken through and there is no separation between the stones and the matrix; whereas where granite or flints are used the matrix invariably leaves the stones quite clean and free from cement mortar.

The weight of 5 to 1 concrete made with Portland stone weighs, three days after being made, 136 lbs. per cubic foot, and after a period of twelve months 128 lbs. per cubic foot, as against 150 to 152 lbs. for granite and 140 lbs. for concrete made with Thames ballast.

The difference in weight means a great saving in the cost of centering, especially where it is necessary to use steel in place of timber; but of course against this has to be placed the cost of getting the broken Portland stone and sand from the stone on to the site of the works.

Proportions for Materials.

The proportions that I should recommend for concrete to be used in concrete arches is 5 to 1, made as follows:—4 parts of broken stone, no piece being larger than 1 inch cube, down to $\frac{3}{8}$ inch, 1 part of sand made from the stone, and 1 part of Portland cement, all by weight; this gives a matrix or mortar of 1 to 1. In the case of Portland stone, the stones should be well soaked in water for at least twenty minutes, when they will absorb nearly 10 per cent. of their weight; the sand and cement must be mixed thoroughly together, then put into a concrete mixing machine with the stones and mixed for about a minute, after which water must be gently sprayed on until the whole mass is in a soft and very plastic condition. This will take at least two or three minutes, when the concrete can be emptied into a trolley, taken to the site of the works, and put into position as soon as possible.

For concrete made from granite, hard stones or Thames ballast, the maximum of water to be used must not exceed $5\frac{1}{2}$ per cent. for 8 to 1 concrete, if the maximum amount of strength is required; for 5 to 1 concrete the water must be increased, owing to the excess of cement taking up more moisture, and this can only be done by heavy and systematic ramming of the concrete. The addition of a large amount of water to concrete made with granite, hard limestones or Thames ballast seriously reduces its strength, because the cement is washed away from the sand and stones and the resultant mixture is very uneven in strength. All the hard stone concretes require a lot of ramming when the minimum amount of water is used.

The proportions that I have found the best for various strengths of concrete where Portland stone and sand from the same is used are as follows:—

(*a*). For 4 to 1 concrete, 3 parts broken stone from $\frac{3}{8}$ inch to 1 inch, 1 part sand from the crushed stone, and 1 part Portland cement, thus obtaining a matrix of 1 to 1.

(*b*). For 5 to 1 concrete, the same proportions as for 4 to 1, but

4 parts of stone instead of 3; this gives a ratio of 1 to 2 for the proportion of sand and cement to stone.

(*c*). For 6 to 1 concrete, 13 parts stone, 4 parts sand and 2·813 cement, giving a matrix of 1 to 1·42 and the proportion of sand and cement to stone as 1 to 1·91.

(*d*). For 7 to 1 concrete, $13\frac{1}{2}$ parts stone, $4\frac{1}{2}$ parts sand and 2·563 cement, giving a matrix of 1 to 1·76 and the proportion of sand and cement to stone as 1 to 1·91.

(*e*). For 8 to 1 concrete, $13\frac{1}{2}$ parts stone, $4\frac{3}{4}$ parts sand and 2·265 parts cement, giving a matrix of 1 to 2·09 and the proportion of sand and cement to stone as 1 to 1·93.

(*f*). For 9 to 1 concrete, 14 parts stone, 5 parts sand and 2·11 parts Portland cement, giving a matrix of 1 to 2·37 and the proportion of sand and cement to stone as 1 to 1·97.

(*g*). For 10 to 1 concrete, $14\frac{1}{2}$ parts stone, $5\frac{1}{2}$ parts sand and 2 parts cement, giving a matrix of 1 to 2·75 and the proportion of sand and cement to stone as 1 to 1·93.

These ratios were obtained by making the concrete so that it worked up well; and when the cubes were crushed it was found that there was sufficient sand and cement to fill all interstices. As a general rule it will be safe, where broken stone is used and the sizes of the stones are from 1 inch maximum down to $\frac{3}{8}$ inch, to make in all cases the proportions of sand and cement 1 to 2 of the stone; but if larger stones be used and very little small stuff, then it becomes necessary to increase the quantity of sand, thereby weakening the concrete if a homogeneous mass is required.

The ratios given are for concrete well rammed; if it be desired to save labour in ramming, the sand must be increased fully 50 per cent. so that all interstices may be filled up. This is however not a method that I should at all recommend where the concrete is to be used in the construction of an arch or of a wall or other work where heavy loads have to be carried.

Tests of Concrete.

The following are the three months' crushing results of the 5 to 1 to 10 to 1 concretes, made in the proportions already given :—

5 to 1 concrete	... ...	215·66	tons per square foot.
6 to 1 ,,	... ...	190·78	,, ,,
7 to 1 ,,	... ...	157·60	,, ,,
8 to 1 ,,	... ...	114·05	,, ,
9 to 1 ,,	... ...	107·83	,, ,,
10 to 1 ,,	... ...	103·68	,, ,,

It will be noted that the difference in crushing is almost in direct proportion to the ratio of the strength of the various matrices. In nearly all descriptions of work the 10 to 1 concrete is strong enough; but, where the surface of the same is exposed to climatic influences, it is advisable to face the work with 1 to 1 cement mortar, brought up as the work proceeds, when your concrete will stand the action of weather as well as 4 to 1 or 5 to 1 concrete in which the matrix is in the proportion of 1 to 1.

In using Portland stone for concrete I strongly recommend the same being thoroughly soaked so that as much water as possible may be absorbed by the stone; you may assume that on an average 10 per cent. of water is taken up, and to this you can add a further 8 to 10 per cent.; the water will not so readily come to the surface as in the case where hard stones and ordinary sand are used.

When the water does rise, it is invariably clear and free from Portland cement. The sand, being also absorbent, retains a large percentage of the water, which enables the cement to perfectly bond all the particles together. The Portland stone sand, when examined under a magnifying glass, is very sharp and angular; and this, combined with its chemical composition and porosity, is no doubt the reason why there is such an affinity between it and Portland cement.

The analysis of Portland stone is as follows:—Moisture, 0·65 per cent.; carbonate of lime, 94·30; sulphate of lime, 0·17; oxide of iron and alumina, 1·70; soluble silica, 0·05; insoluble silica (sand), 1·55; and magnesia alkalies, etc., 1·58; total, 100·00 parts.

When the stone is crushed to sand, made into a plastic state with water, and formed into cubes it will, after a lapse of six weeks or so, take at least 3 to 4 tons per square foot to crush it, showing that there is a certain cementitious property in the sand; this I think is caused by the presence of the soluble silica and alkalies and also the sulphate of lime in the stone.

I have already touched upon the fact that concrete made with Portland stone can be tooled and dressed like ordinary stone; you will readily see what an advantage concrete made from this stone possesses, as, after being formed in position, the faces can be dressed in any way required and, if care be exercised, rock facing can be done even better than with ordinary Portland stone.

Materials to be Weighed, not Measured.

In all my experiments made with concrete I have invariably adopted the rule to weigh all materials, so that the same proportions may be maintained throughout, as I have found that Portland cement varies very considerably in weight. I have discovered during the last four years that the difference per striked cubic foot is as much as from 10 to 12 lbs., so you will note what a difference there will be in the strength of concrete where all materials are mixed from gauging only and not by weight.

In the case of Portland stone, the cement required per cubic yard is 17 per cent. less than when granite is used, and about 14 per cent. less than when Thames ballast is employed. This is due to the difference in weight of the stone and sand; but against this is the astounding fact that, with the reduction in cement, concrete made from Portland stone is, on an average, from 15 to 25 per cent. stronger than that made from granite or Thames ballast; and, if the same quantity of cement per cubic yard were used for Portland stone as is employed for ballast or granite, then the percentage of increase in strength would be greater.

Concrete made with Thames Ballast.

In London and the surrounding districts the usual material employed for making concrete is Thames ballast, and in 99 per cent. of cases the ballast is not freed from any sand unless the contractor is in need of the same; the sand is therefore out of all proportion, being in some cases three times as much as is required for making good concrete. I therefore strongly recommend that, where ballast is used, all the sand should be first removed by screening on a $\frac{1}{8}$-inch mesh sieve, after which the balance in the shape of shingle and flints should be passed through a $\frac{3}{4}$-inch mesh, and the flints, etc., remaining on the mesh should be broken in a stone breaker so as to pass through a 1-inch diameter ring. Concrete made with Thames ballast so treated is, on an average, from 30 per cent. to 40 per cent. (and in some cases 50 per cent.) stronger than when made with the ballast as received, as there are few pebbles; pebbles, being invariably spherical, do not impact so well as broken stones and therefore are unable to withstand crushing to the same extent. I have found when ballast concrete, made from ballast as dredged, is crushed that in nearly all cases the flints leave the matrix as clean as when made into concrete; but when the flints are first broken they are cracked through when the concrete is crushed.

The amount of sand required for concrete made from Thames ballast should be about 25 per cent. in excess of that which I recommend for Portland stone concrete; and, if it be required to make the mass absolutely watertight, the sand may be increased to

50 per cent.; but it must be borne in mind that the minimum amount of water must be used with the maximum amount of ramming to obtain a good resultant mass.

Mixing Machine.

I always recommend that concrete should be made in a concrete mixing machine, as the mass is better mixed than when manual labour is employed and much less water can be used. I prefer a concrete mixing machine in which the process can be seen, and not a closed apparatus. Machines which are closed are not to be recommended, as the resultant mixture can only be seen when emptied; whereas, when the process of mixing is visible, a few extra revolutions can be given if the mass is not mixed to the satisfaction of an inspector. Open machines have also the advantage that, if extra water is needed, the required amount can be added at the discretion of the inspector.

Mixing by Hand.

When concrete is mixed by hand it should be turned at least three times dry and three times wet, and then put into a skip or trolley or thrown into the place required. All workmen should be instructed and compelled to give the shovels a rotary motion when mixing concrete and not to throw it off the shovels as if they were shovelling into a cart, as this latter method does not in any way mix the mass in a proper manner.

Cleanliness of Materials.

I wish now to particularly call attention to the question of cleanliness, and on this point it is impossible to be too particular. As Portland cement has no affinity for dirt in any form whatever, the presence of clay, mud, earth, loam, etc., etc., reduces the strength at least 75 per cent.; in cases where the ballast or stone is very dirty, the strength is only 10 per cent. of that where clean materials are used. This also applies to the water, as mud or other impurities will seriously reduce the strength of the concrete, according to the amount that is held in suspension therein; wherever possible the water employed should be drawn direct from the main; or, if this is impracticable, sea water may be used, or water pumped from a well, or drawn from a river where the purity of the water is assured. I have seen and know of so many failures in concrete work, due to carelessness in the use of water, that I cannot lay too much stress upon the importance of purity in the water used and absolute cleanliness in the materials employed; the strength of the resultant mixture depends entirely upon these two points, combined with thorough mixing, the depositing of the concrete where required as rapidly as possible after being made, good ramming, in hot weather the free application of water and the covering of the surface with sacks laid on battens, and in cold weather the covering of the concrete with sacks to prevent the same being attacked by frost.

Bonding Layers.

There is one more point to which I wish to allude, viz., when concrete is brought up in layers always leave the surface rough; and, if it is not possible to obtain stone figs to bond the several layers together, make depressions in the concrete so that the succeeding layer may bond well and so prevent any sliding on the beds. It is a well-known fact that new concrete put on to old concrete, or concrete that has only been made say for twenty-four hours, is weakest at the joint, and it does not matter how well the surface may be roughened; or if mortar be laid on the existing concrete before the new is put in, the joint will always be weaker than the body of the same; I therefore strongly recommend that great care should be taken in making concrete walls where the loads or pressures are not acting at right angles to the beds. In the case of large masses of concrete, put in for foundations, it is not as necessary to exercise this amount of care; but I think it advisable to do so, as relaxing a rule in one case may cause the same to be overlooked when it is necessary that great care should be exercised.

Grinding Cement.

In the use of Portland cement great care must be exercised in attending to the following rules, viz. :—The cement should be very finely ground so that, when tested in a Goreham's standard flourometer working with an air pressure equal to a 3-inch head of water, a percentage of flour cement will be thrown off equal to not less than 47 per cent. to 50 per cent. of the quantity treated; when passed through a sieve of 180 meshes to the lineal inch with standard gauge wires, the residue retained on the sieve should not exceed 17 per cent., and if this amount is exceeded the cement should have added to it a sufficient quantity of finely ground material so as to bring the same up to the requirements wished for.

My reason for insisting so strongly on this point is due to the result of my experiments extending over long periods upon the strength of sand briquettes and concrete made with finely ground cement as against cements which contained only 28 per cent to 40 per cent. of flour, and 5 to 10 per cent of residue retained on a 76×76 sieve; by reference to the appendices you can easily see what a vast difference there is in strength between concrete made with fine and coarsely ground cements.

Testing Cement.

To prevent any adulterated cement being used special care should be taken, when an analysis of the cement is made, to ascertain that the insoluble residue does not exceed 1 per cent. as a maximum when the cement is made from chalk and clay and burnt in the usual manner with coke, and ½ per cent. for rotatory cement ; if Kentish rag be mixed with the cement as an adulterant it can be detected by the peculiar colour and odour when the same is dissolved by strong hydrochloric acid. Great care should also be exercised in ascertaining that there is no free lime in the cement ; if any is present the cement, before being used, must be aerated until such time as the free lime is dissipated by air slaking.

If possible the magnesia should not in any case exceed 2 per cent when the cement is made from chalk and clay ; but I do not agree with some experts in thinking that an excess of magnesia causes a rupture of the concrete ; I believe that the real cause is due to an underburnt cement when the magnesia is in excess ; I have used cements containing 6 per cent of magnesia, made from natural stone, and the same has stood all tests over a period of two years when salt water was used without showing any falling off in strength, but the cement was well burnt and very finely ground. At the same time I should not use a cement containing 6 per cent. of magnesia if it were possible to obtain a cement which only contained 2 per cent. and under.

The lime contents of a good cement, when the same is very well burnt and with no free lime, should not be more than 63 per cent. as a maximum seven days after the clinker has been ground. A cement with this lime content should be aerated until such time as the lime, by the absorption of moisture from the air, is reduced to 62 per cent., when the maximum strength will be obtained out of the concrete. But under ordinary circumstances it is advisable to keep to a 62 per cent. lime content with an absence of free lime, when there will be no possible chance of any failure in the concrete, assuming that all my previous recommendations as to cleanliness, etc., have been strictly adhered to.

A very simple and effective test for free lime is the "Le Chatelier" instrument, which can be obtained at a cost of about 2s. This instrument, the invention of the French chemist of that name, consists of a brass tube about 1 inch in diameter and split ; attached to this are an arm and a graduated quadrant ; to the free side is fixed an index, which moves easily and registers on the quadrant the amount of free lime in the cement. The process is as follows :— Gauge some neat cement with about 25 per cent. of water, place the instrument on a sheet of glass and fill the tube with the gauged cement, having first tied some string round the tube to prevent the same from expanding. Allow this to set hard for 24 hours, and then boil furiously for 3 hours, when, if any free lime is present in the cement, the same will be registered on the quadrant through the expansion of the cement; if the index should register over 3 lines on the quadrant the cement should be rejected or aerated until such time as the index is lowered to $1\frac{1}{2}$ lines, when the cement will be safe to use. This instrument is so easy to manipulate that an ordinary labourer can carry out the experiment after being instructed how to proceed.

The colour of cement is one of the best tests as to the burning, and also to show whether there has been any adulteration with silver sand or Kentish rag. It should be a bluish grey, after being gauged, immersed in water and broken; if silver sand has been added it can be detected by the crystalline appearance and the lighter grey in the colour; if Kentish rag has been added it imparts a brown tint; this is of course assuming that the cement has been properly burnt, because otherwise the cement will always appear brown in consequence of the deficient burning of the alumina unless colouring matter has been added.

These tests refer to cement made from chalk and Medway clay; but in the cases of cement made from natural stone this rule does not always apply if no colouring matter has been added; foreign manufacturers, however, do colour cement so as to make it resemble what is known as English Portland cement. The colouring matter added does not I think make any difference in the strength of the cement as the percentage added is so small; but it is expensive and adds to the cost of the cement simply to satisfy the wishes of the users. Some manufacturers adulterate Portland cement with soluble slag; and I should recommend all users of Portland cement to obtain a guarantee from them that no slag has been used, as there are so many physical conditions dependent upon the making of good slag, that it is not advisable to use a material which may be the cause of serious mischief taking place when the cement is used for making concrete.

There is one matter in reference to the testing of Portland cement that I should like to see eliminated from all specifications, viz., neat cement tests, which are absolutely fallacious and are for all practical purposes useless; for neat cement is not used *en masse*, and a high neat tensile test is no certain indication that you are going to get good results when the same is made into concrete.

As a rule you may rest assured that, if you take from the cement

50 per cent. of the residues and add sand, you will obtain the same tensile results, and in some cases very much more, especially if the cement is very finely ground. I have found that the finer the cement the less tensile strength will be obtained from the neat briquettes and, if the briquettes are made from all flour cement, the strength falls far below that made with 3 parts of sand and 1 of cement.

The test for Portland cement neat, and also when the same is made into concrete, is the sand test, as cement concrete is always used in compression and not in tension, and I fail to see what earthly use the tensile tests are good for. But, since engineers and architects will have tensile tests, they ought to be confined to sand tests. With reference to the strength, 3 to 1 sand briquettes ought to stand not less than 180 lbs. per square inch seven days old, and not less than 300 lbs. per square inch twenty-eight days old; neat cement being only used to ascertain the setting time and also the presence of free lime, and the general appearance and colour where broken.

I have made very exhaustive experiments to ascertain how much of Portland cement is operative when made into concrete. I have found that all residues retained on a sieve having 160 meshes to the lineal inch are inoperative, and that sand could just as well be added for all the strength that is obtained from the residues; but, when the residues are re-ground to flour, greater strength is obtained than from the flour resulting from the first grinding, and this is due to the fact that the residues are the best burnt and the hardest portion of the clinker. You will now perceive why I so strongly insist on fine grinding; the finer the cement is ground the more of the best material is brought into use for making concrete; also the less chance there is, if free lime is present in the cement, of rupture taking place, because the addition of water to the cement when ground into flour will soon get rid of the free lime, whereas, if the same is in coarsely ground cement, it takes some time for the water to indurate and liberate the free lime.

A great many manufacturers add gypsum to the cement to slow its setting; this has no ill effect upon the cement so long as the gypsum has not been added to an excessive amount and so long as it has been ground so fine that it will all pass through a 160×160 sieve; but, if coarsely ground so as to be retained on a 76×76 sieve, concrete or sand briquettes kept in water for a long period may rupture or blow. Not more than $1\frac{1}{2}$ to 2 per cent. of gypsum should be permitted under any circumstances whatever.

Knowledge of Concrete Making.

I will conclude with these few remarks upon the making of concrete ; learn how to make concrete yourselves ; and make yourselves proficient in the use of the shovel, so that if a workman is not doing his work properly you can take the shovel out of his hand and show him how it ought to be done, not only as regards the mixing but also as to the ramming and other methods required ; the workmen will respect you more, and there will be less chance of the work being scamped, because they will know that you are well up in it and cognizant of every move. I not only apply this rule to concrete work, but to every branch of the Engineering profession, both from the practical and theoretical sides of the work. Manual labour lowers no man ; and one never knows in the Engineering profession how often one may be called upon to do work, especially of this nature, when far away from workshops, etc., etc.

In the Appendices to this paper will be found tabulated sheets showing the effect of coarse and fine grinding, which speak for themselves ; also tests of concrete made with the best Portland cements free from adulteration otherwise than by the addition of $1\frac{1}{2}$ per cent. of gypsum, which is not put in to cheapen the cement but simply to retard its setting action.

PART II.

FERRO-CONCRETE IN ARCHES, ETC.

General Remarks.

I have been specially asked to speak upon ferro-concrete construction as applied to concrete arches and buildings, but I do not propose to go into this question anything like as fully as I have done with regard to pivoted arches.

I have already pointed out to you, in the construction of the model arch, the advantages to be derived from the use of iron when applied to the spandril walls and top tables carrying the roadway and footways.

With reference to the use of concrete in building construction, more especially as regards the use of iron or steel in its composition, it is difficult in a paper of this kind and considering its length to give more than a general outline ; it all depends as to whether the building is required as a private dwelling-house, a factory, or a warehouse, etc., and as to the various loads that have to be carried by the floors, etc.

I have touched already upon so many points, which have reference to the use of iron and steel in the composition of concrete as applied to bridges, that I do not think you will have much difficulty in forming a very fair idea of how iron and steel should be applied so as to strengthen concrete.

In using iron or steel in what is known as ferro-concrete construction it is necessary to adhere strictly to round or ovoid rods ; for the reasons that, owing to their shape, it is so much easier to form with them a perfect bedding in the concrete ; they are much easier to handle than square or flat iron ; and, when bedded in the tension member of a beam or floor, there is not the liability of the concrete cracking when heavy stresses are put in the iron.

In dealing with a ferro-concrete beam, it is necessary to treat it as a beam the tension of which is taken up by the iron and the compression by the concrete. It is not advisable under any circumstances whatever to assume that the concrete is going to take up any tensional stresses, because, should a beam be designed thus and any imperfection be present in the lower or tension member, then undue stresses would be put on the iron, which it might not be able to resist, and the beam would collapse.

In applying iron, great care should be taken that the elastic limit is never reached with maximum loading, otherwise the concrete will invariably crack up to the iron and slightly beyond, and there will be a permanent set in the beam after the load is removed. This would make the beam appear unsafe; but in reality it is not so, as a concrete beam loaded up to its maximum limit, unless the iron or steel has been strained up to and beyond the elastic limit, will always return to its normal state. This is a peculiarity that concrete possesses, which I have observed many hundreds of times when crushing cubes. Ferro-concrete is particularly adapted to insecure foundations by reason that a cill can be formed over the whole area, the thickness of the concrete being reduced to the absolute minimum and the walls formed into huge beams, which will distribute the weights over the whole area of the cill and so reduce the loads on the foundation to a merely nominal amount. But should greater security be required then concrete piles can be driven down until a solid foundation is met with, and upon the top of these piles concrete beams can be made and the walls built in the ordinary way.

Concrete piles possess the advantage over wood or iron that there is no decay; so that when a building is erected upon concrete piles, there is the certainty that no accident is likely to happen, as age improves Portland cement concrete.

The walls of concrete buildings can be made very thin, 4 inches being ample where columns are used to carry the beams and floors; but where columns are dispensed with, then for a building 100 feet high the walls can start at 12 inches and finish at 4 inches at the top; to prevent buckling under heavy loading, iron must be used in its composition.

I know of hardly any form of structure that cannot be constructed in ferro-concrete, even to roof principals, fireproof doors, etc. But the fact must not be lost sight of that, where a fireproof building is required, limestone in any form whatever must not be used for making the concrete, though the outside face as to 1 inch thick may be formed of 1 to 1 Portland stone sand mortar as previously stated. The best materials to stand fire are gravels and granite, but the latter is expensive unless a granite quarry is close at hand. Slag makes good concrete so long as it is not exposed to too much moisture, but immersion in water will cause failure in time.

The following are some illustrations of ferro-concrete bridges.

CHATELLERAULT BRIDGE, FRANCE.

Fig. 1, *Plate* X.

This bridge crosses the River Vienne in France, and is formed entirely of ferro-concrete. It has a central span of 164 feet and two side spans of 135 feet each, with rises of respectively 15 feet 8 inches and 13 feet; and a width between the parapets of 26 feet 3 inches. It cost only £8,000, which works out at 12s. 8d. per square foot of road and footway surface from outside to outside of abutments; and is a marvel of cheapness and strength, considering the amount of material used.

The spans are formed of four arched concrete ribs, 35 inches deep by 19 inches wide at the springings, tapering to 19 inches square at the soffit. The extrados of these ribs are connected together by an arched table extending from outside to outside of the ribs, built at the same time as the ribs. The roadway and footways are supported by spandril pillars 8 inches square, the top table carrying the roadway material being 10 inches thick at the centre, tapering to 5 inches at the kerb, so as to allow for drainage into the channels. The footways, as to three-fourths of their breadth, are cantilevered, the overhang being 3 feet 5 inches. The spandril pillars at the top are connected together by longitudinal concrete beams so as to carry the top table.

This bridge is continuous in its composition from abutment to abutment, and its great strength is due entirely to the judicious use of iron and steel rods in its construction; where there was any possible chance of tensional stresses being set up, due to unequal loading, iron was introduced in order that no possible injury could take place to the concrete. The concrete ribs are carried right through the piers, the interior of the same being filled up with weak hydraulic lime concrete which is much cheaper than Portland cement concrete; it was only required to add weight and not strength to the piers, as the facings of the piers and cutwaters were also made of ferro-concrete. The spandril pillars are likewise wired, and the connection between the same and the ribs is perfect. The longitudinal bearers carrying the top table are treated as continuous beams, as is also the table itself; and the overhanging footways are likewise wired in the tension member to prevent any collapse when subjected to bending.

This bridge is really a skeleton network of iron and steel rods and wires, filled in with concrete to protect the iron and steel from corrosion, the concrete taking all compressive stresses and the iron and steel the tensional stresses.

The bridge only weighs 250 lbs. per foot super, which is less than many arched iron or steel structures. The bridge was subjected to very severe tests, the first being that of loading the roadway with 165 lbs. of moist sand per square foot and the footways with 123 lbs. per square foot.

The maximum depressions were as follows:—$\frac{8}{32}$ inch for the left span, $\frac{7}{32}$ inch for the right span, and $\frac{13}{32}$ inch for the central span; the mean depression for the side arches being $\frac{1}{7300}$ of the span, and for the central span $\frac{1}{5000}$.

The bridge was tested with a rolling load as follows:—One steam roller of 16 tons, two double axle carts of 16 tons and six single axle carts of 8 tons, which, together with the teams, gave a total weight of about 40 tons, were passed simultaneously over the bridge, beside which the footways were loaded with 80 lbs. per square foot.

As a further test 250 infantry were made to cross the bridge in a body, first at cadenced step, then in double quick time. After this a steam roller was passed over the bridge over cleats of wood 2 inches thick, which were strewn in order to produce a series of shocks.

The maxima of depressions attained did not exceed $\frac{1}{9000}$ of the span, so that the equally distributed live load tests were in all cases worse than the rolling loads. After the experiments were completed it was found that there was no permanent deflection in any of the arches; but it was observed that, owing to the method of constructing the arches, viz., continuous from abutment to abutment, a deflection in one arch due to the rolling load caused a rise in the contiguous arch.

Had the bridge been constructed with pivots at the springing and centres I do not think that the deflections would have been so great. Another matter to be considered is that in a pivoted bridge, free movement at the pivots prevents undue stresses owing to temperature being set up; but in a continuous arch, stresses are set up which at times, and with a heavy rolling load, must be severe. Of course if the iron or steel is never strained up to its elastic limit, then there is no chance of failure in any part of the work.

The photograph of this bridge was kindly lent me by Mons. L. G. Mouchel, the London representative of Mons. Hennebique, who designed the structure.

The following are short descriptions of other ferro-concrete bridges constructed on the Hennebique system, all on the continent of Europe.

BADE BRIDGE, NEAR VIENNA.

Fig. 2, *Plate* X.

This bridge, erected at Bade, near Vienna, has a clear span of 77 feet 5 inches, with a rise of 7 feet 9 inches or $\frac{1}{10}$. It is composed of four arched beams about 16 inches in thickness. The floor is carried on the said beams and also on intermediate cross beams which tie the whole structure together.

The abutments are formed of ferro concrete and ordinary concrete *en masse*, and the maximum load on the foundations when the bridge is fully loaded does not exceed 2 tons per square foot.

PEÑA BRIDGE, BILBAO, SPAIN.

Fig. 3, *Plate* X.

It was originally intended to construct this bridge of stone, but the Spanish habit of putting off everything until "to-morrow" prevented it being built in anything but ferro-concrete, as it was necessary to have the bridge completed in three months after the authorities had come to a final decision.

It is 471 feet long over all, and is composed of four piers and five spans of 82 feet each, with a rise of $\frac{1}{8}$. The ribs are only 18 inches deep at the centre.

Owing to the presence of a factory which the authorities would not purchase the bridge was curved on plan, which is clearly seen on the photographic reproduction.

This bridge carries a line of electric tramway, besides having two footways for passengers. The piers were made abnormally strong, so as to withstand the shocks caused by large trees which are brought down the river in time of flood.

FOOTBRIDGE AT ROTTERDAM, HOLLAND.

Fig. 1, *Plate* XI.

The span of this footbridge, which crosses a very wide road at Rotterdam in Holland, is about 98 feet 5 inches, and is formed of two arched beams, with top table and cross beams.

All the supporting columns, stairs, etc., etc., are made of ferro-concrete.

Road Bridge near Strassbourg, Germany.

Fig. 2, *Plate* XI.

I am not in a position to give any dimensions of this bridge, but it was constructed of ferro-concrete and made to imitate a bowstring girder. The abutments were made of ferro-concrete sheet piles, the grooves being filled with neat cement grout. The photograph shows that the cross beams or girders are of concrete, and evidently the usual road covering has been employed.

L'Echez Bridge, Hautes-Pyrénées, France.

Fig. 1, *Plate* XII.

This small bridge has three small spans of 42 feet $4\frac{1}{2}$ inches, with rises of about $\frac{1}{10}$. The arch ring is solid, with external and internal spandril walls carrying the road and footways. The bridge is made sufficiently strong to carry a distributed live load of 2 cwts. per square foot, and also a rolling load of 20 tons, which is the test usually adopted in France.

Boubre Bridge, France.

Fig. 2, *Plate* XII.

This bridge, erected across a small river in the South of France, shows how satisfactorily ferro-concrete may be employed in the construction of an ordinary beam. The span is 45 feet 11 inches, the depth of the beam being 4 feet, and the thickness only 14 inches. The floor is 7 inches in thickness with cross secondary beams.

The bridge was tested with an equally distributed live load of 1 cwt. per square foot and a rolling load of 8 tons, and also with a rolling load of 20 tons but without any distributed load. The deflection was very small.

Kamennataia Bridge, Russia.

Fig. 3, *Plate* XII.

The peculiarity about this bridge is the enormous strength of the piers as compared to the superstructure, the reason being that the Russian authorities required large cavities in the piers which could be filled with dynamite for an effectual destruction of the bridge in time of war if found necessary. The bridge is made sufficiently strong to carry the heaviest artillery.

Dora Bridge, Italy.

Fig. 1, *Plate* XIII.

This plate only shows one unfinished span of a two-span bridge in the province of Turin.

The bridge is erected on the skew at an angle of 63° 15′, with spans of 66 feet 5 inches, the rises being $\frac{1}{10}$.

The arch rings are solid, with external and internal spandril walls; the top tables are 7 inches thick with secondary cross beams.

The bridge was tested with an equally distributed load of $125\frac{1}{2}$ lbs. per square foot and a rolling load of a road roller weighing 20 tons. The measured deflection amounted to 2 millimètres or 1·7300 of the span, which is very little.

Soissons Bridge, France.

Fig. 2, *Plate* XIII., *and Plate* VII.

This is a combined railway and road bridge, and is the latest bridge erected in France on the Hennebique system of ferro-concrete.

The total length is 249 feet, composed of three spans; the centre span is 80 feet, and there are two side spans of 79 feet 6 inches each; the angle of skew is 30°.

The total width is 46 feet 7 inches, the railway occupying 16 feet 1 inch, and the roadway being 19 feet 8 inches with two footways each 5 feet 1 inch wide. The bridge is composed of seven arched beams in ferro-concrete, with transverse beams carrying the top table, which in turn supports the road material; the table is 7 inches thick.

The bridge was tested, with most satisfactory results, in the usual severe manner adopted by the authorities in France.

Bormida Bridge, near Millesimo, Italy.

Fig. 3, *Plate* XIII.

This is, I believe, the largest span bridge made of either concrete or ferro-concrete.

The abutments form part of an old three-span arched bridge which was carried away during a very heavy flood. As the bridge was on one of the principal highways it became necessary to reconstruct it as soon as possible and in the shortest possible time. It was decided to construct a single span ferro-concrete bridge, having a clear span of 167 feet 3 inches with a rise of 16 feet $5\frac{1}{2}$ inches or $\frac{1}{10}$.

The bridge is composed of four arched ribs, decreasing from 3 feet 7 inches deep at the springing to 1 foot $7\frac{1}{2}$ inches at the centre, by 20 inches thick. The construction is similar in every way to that of the Chatellerault Bridge which I have previously described.

It was executed in the short space of sixty-seven days; and thrown open to traffic after having been subjected to the following tests:—

The whole of the bridge was covered with 226 lbs. per square foot or 286 tons for the entire span, when the measured deflection was $\frac{7}{16}$ of an inch or 1:4600 of the span; when the load was removed there was no permanent set.

CONCLUSION.

I trust that in this paper I have shown that Portland cement concrete is a most admirable material for use in arches and other forms of construction; and that, where ordinary care is used in its making, its lasting nature, great strength, adaptability to all forms both plain and ornamental and also its non-conductivity and fire-resisting qualities will always give entire satisfaction not only to the designer of the structure but also to the user.

I cannot close this paper without again impressing upon you the absolute necessity for cleanliness in the use of the materials employed, the purity of the water used, the efficient mixing and ramming of the concrete, its protection from sun and cold during construction and, last but not least if lasting structures are required, the necessity of obtaining at whatever cost the very best unadulterated Portland cement that is made.

APPENDICES.

I.—RESULTS OF CONCRETE EXPERIMENTS.

NOTE.—In all cases throughout these tables where the word "matrix" is used it refers to the proportion of cement to sand which is required to fill up all interstices in the concrete and so bond the mass together.

(A). CONCRETE OF DIORITE, OR WHAT IS KNOWN AS GUERNSEY GRANITE.

(i.). 4 to 1 concrete. Age 9 months. Lowest crushing 125½ tons; highest 137½ tons. Average of 4 cubes 131¼ tons per square foot. Matrix used 1 to 1.

(ii.). 4 to 1 concrete. Age 12 months. Lowest crushing 166¾ tons; highest 229 tons. Average of 13 cubes 198 tons per square foot. Matrix used 1 to 1.

(iii.). 4 to 1 concrete. Age 13 months. Lowest crushing 123 tons; highest 193 tons. Average of 22 cubes 153 tons per square foot. Matrix used 1 to 1·32.

(iv.). 4 to 1 concrete. Age 3 years and 10 months. Lowest crushing 176·76 tons; highest 249·11 tons. Average of 8 cubes 207·68 tons per square foot. Matrix used 1 to 1.

(v.). 5 to 1 concrete. Age 12 months. Lowest crushing104 tons; highest 124½ tons. Average of 5 cubes 114 tons per square foot. Matrix used 1 to 1·75. Excess of water.

(vi.). 5 to 1 concrete. Age 12 months. Lowest crushing 142·50 tons; highest 158·75 tons. Average of 4 cubes 147·75 tons per square foot. Matrix used 1 to 1·75, made dry and required very heavy ramming.

(vii.). 5 to 1 concrete. 3 years and 10 months old. Matrix and other conditions same as for previous test. Lowest crushing 176·78 tons; highest 214·95 tons. Average of 3 cubes 192·18 tons per square foot.

(viii.). 6 to 1 concrete. 2 years and 9 months old. Crushing of 1 cube 134 tons per square foot. Matrix used 1 to 1·75.

(ix.). 6 to 1 concrete. 3 years and 10 months old. Lowest crushing 154·68 tons; highest 190·84 tons. Average of 10 cubes 166·13 tons per square foot. Matrix used 1 to 1·75.

(x.). 8 to 1 concrete. 3 years and 10 months old. Lowest crushing 124·55 tons; highest 170·76 tons. Average of 6 cubes 148·32 tons per square foot. Matrix used 1 to 2·66.

NOTE.—The granite or diorite used in the above tests was broken to pass through a ½-inch mesh, and is known as ⅜-inch granite spalls; the sand used was obtained from the crushed stone.

All the above tests were made with stone and sand which had been washed perfectly clean so that there was not one particle of dirt adhering to the same. In practice the care that was exercised in making these tests could not, without much expense, be carried out, so that the above must be taken as the highest results that could be obtained where diorite is used.

The ramming throughout was heavy and the water used the minimum, unless otherwise stated.

Diorite is not to be recommended as it is too hard, and the faces too smooth when the stone is broken; moreover it weighs about 154 lbs. per cubic foot when made into concrete.

(B). THAMES BALLAST CONCRETE.

This concrete was made with ballast as received, no sand being eliminated.

(i.). 8 to 1 concrete. All by weight:—

Age.	Lowest crushing in tons per square foot.	Highest crushing in tons per square foot.	Number of cubes tested and average crushing in tons per square foot.
7 days ...	*33·00	74·50	9 cubes 49·09 tons.
14 ,, ...	43·50	99·50	10 ,, 62·25 ,,
21 ,, ...	*44·00	103·30	10 ,, 72·63 ,,
28 ,, ...	*42·00	110·00	11 ,, 73·33 ,,
35 ,, ...	49·00	124·50	9 ,, 88·25 ,,
42 ,, ...	89·00	155·50	8 ,, 101·75 ,,

* These cubes had been exposed to the sun's rays.

(ii.). 8 to 1 concrete. All by weight, the excess sand eliminated, and flints broken to pass through a $1\frac{1}{2}$-inch mesh :—

Age.	Lowest tons per square foot.	Highest tons per square foot.	Average tons per square foot.
7 days ...	40·00	114·05	8 cubes 65·91 tons.
14 ,, ...	52·25	155·53	8 ,, 86·86 ,,
21 ,, ...	72·50	174·19	8 ,, 111·19 ,,
28 ,, ...	74·65	155·53	8 ,, 116·65 ,,
35 ,, ...	87·00	188·71	8 ,, 129·85 ,,
42 ,, ...	72·50	165·89	8 ,, 122·10 ,,

NOTE.—The great difference between the highest and lowest crushing is due to the fact that in the lowest the stones did not lay well, whereas in the highest the stones packed well and lay flat. All cubes were made at the same time and from the same gauging.

(iii.). 6 to 1 concrete made with ballast as received, no sand eliminated :—

Age.	Lowest crushing in tons per square foot.	Highest crushing in tons per square foot.	Number of cubes tested and average crushing in tons per square foot.
7 days ...	31·00	75·00	6 cubes 50·16 tons.
14 ,, ...	47·00	100·00	6 ,, 64·75 ,,
21 ,, ...	*21·00	133·00	7 ,, 70·57 ,,
28 ,, ...	*50·00	103·50	7 ,, 78·85 ,,
35 ,, ...	*54·00	114·00	6 ,, 86·83 ,,
42 ,, ...	*60·00	114·00	7 ,, 81·72 ,,

* These cubes had been exposed to the sun's rays.

(iv.). 6 to 1 concrete. Excess sand eliminated and flints broken as before :—

Age.	Lowest.	Highest.	Number of cubes and averages.
7 days ...	41·47	101·63	14 cubes 73·20 tons.
14 ,, ...	66·36	126·49	14 ,, 93·77 ,,
21 ,, ...	55·99	155·53	14 ,, 106·48 ,,
28 ,, ...	62·21	180·41	14 ,, 113·17 ,,
35 ,, ...	83·00	211·52	14 ,, 126·21 ,,
42 ,, ...	82·95	174·00	13 ,, 131·20 ,,

(v.). Table showing the difference between 8 to 1 concrete made with Thames ballast as received and concrete made with excess sand eliminated and flints broken to pass through a $1\frac{1}{2}$-inch mesh:—

Age.	With ballast as received.	Excess sand eliminated and flints broken.	Difference being in favour of less sand and broken flints.
7 days ...	49·09 tons	65·91 tons	+ 16·82 tons per sq. foot.
14 ,, ...	62·25 ,,	86·86 ,,	+ 24·61 ,, ,,
21 ,, ...	72·63 ,,	111·19 ,,	+ 38·56 ,, ,,
28 ,, ...	73·33 ,,	116·65 ,,	+ 43·32 ,, ,,
35 ,, ...	88·25 ,,	129·85 ,,	+ 41·60 ,, ,,
42 ,, ...	101·75 ,,	122·10 ,,	+ 20·35 ,, ,,

(vi.). Table showing the difference between 6 to 1 concrete made with ballast as received and that with excess sand eliminated and flints broken :—

Age.	With ballast as received.	Excess sand eliminated and flints broken.	Difference being in favour of less sand and broken flints.
7 days ...	50·16 tons	73·20 tons	+ 23·04 tons per sq. foot.
14 ,, ...	64·75 ,,	93·77 ,,	+ 29·02 ,, ,,
21 ,, ...	70·57 ,,	106·48 ,,	+ 35·91 ,, ,,
28 ,, ...	78·85 ,,	113·17 ,,	+ 34·32 ,, ,,
35 ,, ...	86·83 ,,	126·21 ,,	+ 39·38 ,, ,,
42 ,, ...	81·72 ,,	131·20 ,,	+ 49·48 ,, ,,

(vii.). Table showing the difference between 6 to 1 concrete made with ballast as received and 8 to 1 concrete with excess sand eliminated and flints broken :—

Age.	6 to 1 concrete with ballast as received.	8 to 1 concrete with excess sand eliminated and flints broken.	Difference being in favour of 8 to 1 concrete with less sand and broken flints.
7 days ...	50·16 tons	65·91 tons	+15·75 tons per sq. foot.
14 ,, ...	64·75 ,,	86·86 ,,	+22·11 ,, ,,
21 ,, ...	70·57 ,,	111·19 ,,	+40·62 ,, ,,
28 ,, ...	78·85 ,,	116·65 ,,	+37·80 ,, ,,
35 ,, ...	86·83 ,,	129·85 ,,	+43·02 ,, ,,
42 ,, ...	81·82 ,,	122·10 ,,	+40·38 ,, ,,

NOTE.—This table clearly shows that the 8 to 1 concrete made with broken flints and the minimum amount of sand is very much superior in strength to the 6 to 1 concrete made with the ballast as received.

(viii.). 8 to 1 Thames ballast concrete made with dirty ballast :—

3 cubes 7 days old averaged 8·25 tons per square foot.

3 cubes 28 days old averaged 22·66 tons per square foot.

NOTE.—See ordinary tests for 8 to 1 concrete where clean ballast was used.

(C). Concrete of Portland Stone.

(i.). 5 to 1 concrete made with 4 parts of broken Portland stone $\frac{3}{8}$ inch to 1 inch, with 1 part of sand crushed from the stone and 1 part of Portland cement, all by weight.

The stones were soaked until they absorbed 10 per cent. of water; another 6 per cent. was added to make the concrete very plastic.

7 days old;	crushing weight	= 107·75	tons per square foot.
14 "	"	= 155·50	" "
21 "	"	= 163·82	" "
28 "	"	= 197·00	" "
3 months old;	"	= 188·71	Average 190·78.
"	"	= 197·00	
"	"	= 186·63	
6 months old;	"	= 192·86	Average 192·86.
"	"	= 188·71	
"	"	= 197·00	
9 months old;	"	= 234·33	Average 237·79.
"	"	= 232·26	
"	"	= 246·77	
12 months old;	"	= 223·96	Average 243·32.
"	"	= 250·92	
"	"	= 255·07	

Note.—As concrete takes about 3 to 4 years to attain its maximum strength, it is safe to assume that fully 50 to 75 tons per square foot could be added to the 12-months tests to give the ultimate and constant crushing strength of the concrete when made in small cubes.

(ii.). 5 to 1 concrete as before, but washed Thames sand used in place of Portland stone sand.

29 days' crushing results :—

165·89, 167·97, 208·22, and 197·05

tons per square foot. Average 183·53 tons per square foot, as against 197 tons per square foot where oolite sand was used; the result is most satisfactory.

(iii.). 5 to 1 concrete as before, and with Portland stone sand, the same being passed through a 30 × 30 sieve and all grit retained thereon being thrown on one side. The results show a great falling off in strength, due to the abnormal fineness of the sand.

29 days' results :—

153·45, 147·23, 136·86, and 130·64

tons per square foot. Average 142·04 tons per square foot, as against 197 tons per square foot where all coarse grit was included. But when the tests are carried on for 12 months I have found that there is only a falling off of about 10 per cent. in the crushing results.

(D). Tests of Matrix of 1 Oolite Sand to 1 Portland Cement.

Crushing results of the matrix used throughout in making 4 to 1 and 5 to 1 Portland stone concrete ; the proportion being 1 part Oolite sand and 1 part Portland cement, all by weight.

4 months old ;	crushing weight	= 352·50 tons per sq. ft.
4 months and 11 days old ;	,,	= 323·50 ,, ,,
4 ,, ,, 11 ,,	,,	= 302·76 ,, ,,
5 ,, ,, 13 ,,	,,	= 401·33 ,, ,,
13 ,, ,, 3 weeks old ;	,,	= 414·74 ,, ,,

Note.—Concrete made with this proportion of cement to sand could be safely trusted to carry a working load of 100 tons per square foot if used in an arch or columns, etc. The stone from which the sand was made crushed on its bed at 160 to 170 tons per square foot. If iron or steel were used in combination 200 tons per square foot might be put on with safety.

(E). Experiment to Show the falling off in Weight of a Cubic Foot of 4 to 1 Portland Stone Concrete, due to Evaporation of the added Water :—

12″ × 12″ *Cube made* 5. 2. 1900.

Weight	8 February, 1900	= 136	lbs. per cubic foot.
,,	13 ,, ,,	= 134¾	,, ,,
,,	19 ,, ,,	= 133¼	,, ,,
,,	26 ,, ,,	= 132¼	,, ,,
,,	5 March, ,,	= 131¼	,, ,,
,,	12 ,, ,,	= 130¾	,, ,,
,,	27 ,, ,,	= 130	,, ,,
,,	10 April, ,,	= 129¾	,, ,,
,,	3 November, ,,	= 128¾	,, ,,
,,	5 February, 1901	= 128	,, ,,

The amount of water that was permanently taken up by the crystalization of the cement in setting amounted to 3 lbs. About 40 per cent. of the added water is thrown off during the first 3 days. Portland cement takes up approximately 11 per cent. of water due to crystalization, and this is permanently retained.

(F). Effect of Cold on Concrete.

Table showing the effect of cold on concrete made with Portland stone in the proportion of 3 parts stone, 1 sand and 1 cement. All the cubes were made on December 4th, 1900, and placed on the top of a building on 11th December, 1900. The cold had a deterrent influence, but the advent of warm weather restored all the strength :—

	Maximum cold or heat.	Date when crushed.	Age.	Tons per square foot at which the cube collapsed.
1	12° frost	13th Feb., 1901	10 weeks & 1 day	197·00 Block freezing
2	10° ,,	26th Mar., ,,	16 ,,	141·00 Block freezing
3	114° F. in sun	22nd April, ,,	20 ,,	149·30
4	80° ,,	16th May, ,,	23 ,, & 3 days	206·00
5	65° ,,	22nd Sept., ,,	42 ,, & 4 ,,	257·14
6	40° ,,	4th Dec., ,,	52 ,,	273·73

(G). Effect of Grinding Cement.

Experiments made to show the effect of fine and coarse grinding of Portland cement, when used for sand briquettes and also for concrete. These experiments were made with cement which, when received, contained only 28·00 per cent. of flour as tested by Goreham's standard flourometer, with an unground residue of 72·00 per cent.; the residues retained on a 76 × 76 sieve being 10 per cent., and on a 100 × 100 sieve 19 per cent.

The sand used was made from Portland stone and had been passed through a 20 × 20, and retained on a 30 × 30, sieve ; this is the standard size for sand used in making sand briquettes.

(i.). 3 to 1 sand briquettes, 28 days old, using the cement as received.

Tensile results :—215, 215, 235, 235, 220, 220, 215, 200, 215 and 245. Average 221½ lbs. per square inch.

(ii.). 3 to 1 sand briquettes, 28 days old, using cement which had been re-ground to *nil* on a 100 × 100 sieve.

Tensile results :—430, 470, 395, 445, 400, 430, 390, 435 and 395. Average 422½ lbs. per square inch.

(iii.). 3 to 1 sand briquettes, 28 days old, using cement which had passed through a 200 × 200 sieve, the residue being rejected.

Tensile results :—380, 430, 545, 490, 510, 425, 415, 500, 450 and 505. Average 465 lbs. per square inch.

(iv.). 3 to 1 sand briquettes, 28 days old, using flour cement, thrown off by Goreham's flourometer.

Tensile results :—495, 425, 525, 570, 510, 470, 420, 475, 460 and 560. Average 491 lbs. per square inch.

(v.). 3 to 1 sand briquettes, 28 days old, made with flour obtained from re-grinding the residues.

Tensile results :—600, 610, 550, 545, 545, 590, 560, 585, 635, 585, 590, 540, 610, 580, 590, 550, 605, 575, 595 and 590. Average 581½ lbs. per square inch.

(vi.). A 3 to 1 sand briquette, 3 months old, made with flour cement from re-ground residues which had been kept in air during the whole period, broke at **950 lbs.** per square inch.

(vii.). 5 to 1 oolite concrete, proportions as before.

28 *Days Crushing Tests.*

Made with cement as received. Tons per square foot.	Made with cement re-ground to *nil* on 100 × 100 sieve. Tons per square foot.	Made with flour cement extracted from the cement as received. Tons per square foot.
116·13	157·60	
128·57	124·42	165·90
134·79	155·53	
	176·27	
Average.	Average.	
126·49	153·45	

(viii.). 3 months tests of 5 to 1 concrete made with flour extracted from the cement as received.

Crushing results :—176·26, 151·38, 165·89, 170·04, 182·48, 182·48, 199·07, 157·60, 161·75. Average 171·88 tons per square foot.

(ix.). 28 days tests of 5 to 1 concrete made with flour extracted from re-ground residues.

Crushing results :—157·60, 157·60, 174·19 and 174·19. Average 165·89 tons per square foot.

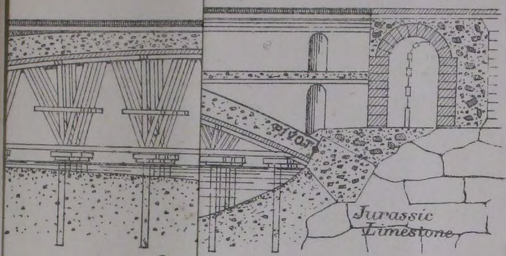
NOTE.—In extracting the flour from cement by Goreham's flour-ometer, the cement is aerated in about 30 minutes to such an extent as to reduce the lime contents as much as 3 per cent. ; if the cement were in the first instance ground to flour, the crushing results would be very much higher. The above results show how much more strength is obtained from Portland cement when the same is ground very fine. If the experiments were continued over a period of two years the difference would be much more marked, as concrete made from finely ground cement increases in strength much more rapidly than that in which coarse cement is used ; the latter attains its maximum strength at a much earlier period unless the concrete is kept in water, when induration will in time break up the coarse residues ; but even then very little ultimate strength is obtained, whereas, when the residues are ground very fine, they all act, even if the concrete is kept in air or in a dry place.

II.—LIST OF PLATES.

MUNDERKIN

PLATE I.

DETA



Span
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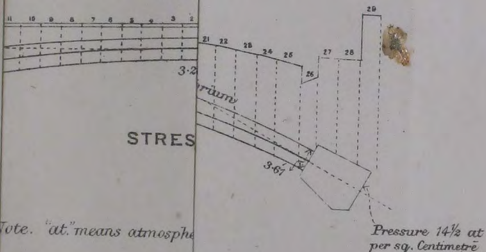

STRES

Note. "at." means atmosphe

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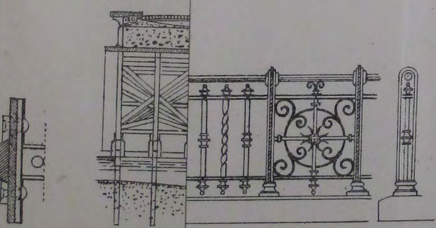


RAPET.

PROFESSIONAL PAPERS OF THE ROYAL ENGINEERS.

PAPER III., VOL. XXIX. 1903.

OIL ENGINES, HEAVY & LIGHT OILS, FOR TRACTION WORK & MOTOR VEHICLES:

COMPARISON BETWEEN THEM AND ELECTRICALLY-DRIVEN VEHICLES FROM ECONOMIC POINTS OF VIEW.

(Lecture delivered at the School of Military Engineering, Chatham, on 19th February, 1903, by MAJOR F. L. LLOYD, R.E.).

LIST OF PLATES.

OIL MOTORS FOR TRACTION PURPOSES.

It was as recently as 1885 that Herr Gottlieb Daimler patented his high-speed petroleum engine, and so opened the door to the development of the motor vehicle of the present day.

At first the development was slow, and not till 1889 was a practical four-wheeled motor carriage put upon the roads, although several motor bicyles and tricycles had been built.

The French, represented by the firms of Panhard et Levassor and Peugot, and the Germans by Benz, soon went ahead; and, restricted by no legislative obstruction and national antipathies to progress, made rapid and wonderful strides.

In England, even hampered as they were, a few daring spirits braved police persecution and public obloquy in their endeavours to keep in touch with what they in their wisdom saw to be the locomotion of the future.

To men such as Sir David Salomons, F. Butler, Knight, Simms, C. S. Rolls, T. B. Elliot, W. B. Avory and Mark Mayhew, we owe the tardy and grudgingly granted act of 1896 which made the light locomotive a legal user of our highways.

To-day, little over six years after the passing of that act, we look upon it as obsolete and ridiculous, and wait anxiously for the removal of restrictions which still check the movement of what has become one of the greatest industries in less hampered nations.

To-day, even the rulers of the British Army, always cautious in taking up new and untried schemes, are seriously considering the extension of the motor transport for Military purposes.

The age is becoming daily more mechanical; our gardeners now run our engines and charge our accumulators; the butler, or even the housemaid, is versed in the mysteries of switches and fuzes and knows how to act when a main fuze blows out.

The gentleman of leisure, who yesterday would have laughed at the idea of understanding anything approaching the mechanical, will now draw a piston, take up bearings, and discourse with knowledge and intelligence upon the properties of steel and wrought iron.

To us, whose duty it is to lead in all things mechanical in the Army, it is therefore of the greatest importance that we do not stand still as others advance in mechanical knowledge. The whole Army will in a few years be users of mechanically propelled vehicles. Each Regiment and Department will possess, and run for itself, its motor vehicles. We cannot expect, and must not expect, to be in future the only mechanics of the Army. But what we must do is to lead in mechanical ideas, and to keep ahead of the rest of the Army in such matters; so that it may always be the instinct in the future, as it has been in the past, when things go wrong and difficulties arise, to send for the Sapper to put them right.

I make this preface as a reason rather than an apology for dealing entirely with technicalities in the rest of my paper, and will at once attack the dry details of the internal combustion engine.

The motive power of a modern oil engine is obtained by the rapid expansion by explosion of air mixed with petroleum vapour (or "carburetted" as it is termed).

In order to obtain this explosion, it is necessary first to compress and then to fire this mixture.

Otto Cycle.

Plate I.

Nearly all oil motors employed in self-propelled vehicles are worked upon the Otto Cycle.

This cycle comprises in a single-ended cylinder the four following piston strokes:—

First forward Stroke of Piston or *Suction Stroke.*—Carburetted air admitted (*Fig.* 1).

First return Stroke of Piston or *Compression Stroke.*—Charge is compressed to about 45 lbs. per square inch (*Fig.* 2).

Second forward Stroke of Piston or *Working Stroke.*—Caused by the explosion of the charge (*Fig.* 3).

Second return Stroke of Piston or *Scavenging Stroke.*—Gases of explosion are expelled (*Fig.* 4).

Thus there is only one working stroke in every four (two forward and two return) and only one impulse to every two revolutions of the crank shaft.

For this reason a heavy fly-wheel is necessary, though the weight of this may be reduced by the now very usual practice of employing two, three, four and even (in some cases) six and eight cylinders, with their pistons all driving the same crank shaft.

These pistons work at very great speed, 600 revolutions per minute being now-a-days very low, and in some cases engine speeds of 2,000 and even 3,000 revolutions per minute being attained.

Other forms of motors have been designed and are made.

Two-Stroke Cycles—Loyal, Conrad, Dufour, Etc.

Two-stroke cycle motors are employed by Loyal, Conrad, Dufour and others. In these the carburetted air is usually compressed in the crank chamber by the forward movement of the piston, and then let into the cylinder above the piston just as the latter reaches the end of its return stroke, and is at once fired, pushing forward the piston again and compressing the next charge in the crank chamber, the exploded gases being driven out through a port by the return stroke of the piston.

Duryrea System.

In another system, the Duryrea, explosion takes place in a special tank acting the part of the boiler of a steam motor and supplying the cylinder with gases under pressure.

Compound Motors.

Finally, reference must be made to the efforts to construct a compound motor in which the gases exploded in the high pressure cylinders (which are usually discharged still under considerable pressure) are utilized to drive forward a low pressure piston in a cylinder of greater diameter than those in which the explosions take place.

This system has the advantage of:—

(1). Utilizing the whole of the power of the explosive mixture of air and gas.

(2). Doing away with the necessity of providing any further arrangements for gradually expanding the exhaust gases from the H.P. cylinders to the pressure of the atmosphere.

And (3) thereby cooling these exhaust gases and discharging them cold into the air, a most important point when motors are used in the presence of highly imflammable gases, as is the case in navigable balloons using hydrogen gas to support them.

Four-Stroke Motor.

I shall, however, confine my further remarks to the four-stroke motor, as that is the most common, and at present the most successful, type made.

This motor consists of one or more single-ended cylinders, which may be vertical, horizontal or inclined, the latter being now very seldom employed; these cylinders are of steel or soft cast iron.

The enclosed end of the cylinder is called the combustion chamber, and it is here that the charge of carburetted air is fired. Connected with it are the inlet and exhaust valves, and within it is the sparkling plug (or other device) by which the compressed gas is fired at the proper moment.

In each cylinder works a malleable cast-iron piston; these pistons are very long, so as to be self-guiding, and are usually prolonged by a hollow sleeve; on the outer face of the piston grooves are cut in which (to insure a tight fit into the cylinder) are lodged rings of copper, malleable iron or, better still, of ordinary cast iron. The rings should quite fill the width of the grooves without being tight, as this would destroy their elasticity.

The piston is connected to the crank of the crank shaft by a connecting rod, there being no piston rod. The connecting rod is usually attached to the piston by a pin, which runs right through the latter and which is closed by the eye of the rod. From the crank shaft the power is transmitted to the vehicle through mechanism, the details of which do not come within the scope of this paper.

I have said that the cylinders may be arranged horizontally or vertically.

The advantage of horizontal cylinders is that by their use it is possible to balance the movements of the pistons and so reduce vibration to a minimum. Lubrication can also be more nicely adjusted and spread over the whole of the wearing surface of the piston.

A disadvantage is that, in an engine having more than two cylinders, it is difficult to arrange the mechanism so that it is readily accessible.

It is stated that horizontal cylinders become oval owing to the weight of the piston, but I believe this to be a myth. Cylinders may wear oval; but it would seem that this is more likely to be due to the pressure of the pistons on them, owing to the angular motion of connecting rods, than to the weight of the pistons themselves.

If this is so, vertical as well as horizontal cylinders are liable to become oval, and I believe that this is the case.

The main advantages of the vertical engine are that it is more easily arranged so as to be accessible and that with it "splash lubrication," which will be referred to later, can be employed. It is almost universally employed on the Continent, but in England some of our best manufacturers prefer the horizontal type. (*Figs.* 1 and 2, *Plate* II.).

The exhaust and sometimes the inlet valves are actuated by cams on a shaft driven at half the speed of the engine; this shaft is geared to the crank shaft by means of toothed wheels. (*Figs.* 3 and 4, *Plate* II.).

INTERNAL COMBUSTION PETROLEUM ENGINES.

There are seven main points which have to be considered in dealing with an internal combustion petroleun engine :—

(1). Carburettion, or the mixing of the petroleum vapour with air.

(2). The admission of this mixture into the cylinder.

(3). The ignition of the carburetted and compressed air.

(4). The cooling of the cylinder.

(5). The methods of dealing with the exhaust gases.

(6). The control of the motor.

(7). Lubrication.

To take these in order :—

(1). *Carburettion.*

It is in this respect that motors employing petroleum spirit and those employing petroleum of a lower specific gravity and of a higher flash point mainly differ, and I will deal with them separately.

Petroleum Spirit.

Petrolem spirit, known as motor spirit, gasolene, petrol and many other names, but usually as gasolene in America, essence in France, and petrol in England, is a distillation of crude petroleum obtained between 70° and 120° C. the density or specific gravity of which varies from about ·675 to 0·710, that most commonly used in England having a specific gravity of ·680 at 60° F. This spirit is highly volatile, and consequently requires very careful packing, handling and transportation.

It cannot be too strongly impressed upon users of petrol, that they should handle this spirit cautiously and far away from any flame.

Its very volatility however is the chief reason why it is so much more used for the engines of motor vehicles than the safer oils.

The preparation of the carburetted air is a comparatively simple process when the volatile spirit is used.

Carburettors may be distinguished as—

(*a*). Bubbling Carburettors in which the air is driven through the liquid petrol and takes vapour away with it. These are not much employed now.

(*b*). Surface Carburettors, in which air is passed over the surface of the liquid spirit.

This system works well but requires much hand adjustment and is liable to disturbance should the surface of the petrol be much agitated by the oscillations of the vehicle.

(*c*). Wick Carburettors, of which the Lanchester (*Fig.* 1, *Plate* III.) is a good and satisfactory specimen.

(*d*). Float Feed Spray Carburettors, which are by far the most common, and of which the Daimler carburettor (*Fig.* 2, *Plate* III.) is a simple and characteristic specimen.

The use of petrol, however convenient in a gentleman's automobile, or in a delivery van or lorry working in a civilized country where stores of petrol can always be relied upon and where this spirit can be transported and stored safely, is almost impossible for Military purposes—especially for us whose fields of action are so wide and so distributed amongst countries of varied temperatures, where any fuel used may have to be transported by train, traction wagon or cart, be roughly handled, and often carried amongst inflammable material and surrounded by men smoking or cooking their food in close proximity.

Of course steel tubes could be made strong enough to resist the roughest of handling, but this is an expensive business and would greatly confine the sphere of action of self-propelled vehicles in the field.

It is therefore of the greatest importance that we should obtain a satisfactory engine using only an oil of high flash point

Many vaporizers for heavy oil have been made. In all the most successful the guiding principle is the breaking up of the oil by spraying or trituration in presence of warmed air which moves rapidly over heated surfaces on its way to the engine cylinder. The atomizing action is an important part of the process, though it may be sufficiently carried out by a very simple means, such as admitting the oil through small holes or round the edges of a mushroom valve.

The air and oil must be well warmed, moved at a high velocity, and twisted round corners as much as possible in order that the oil may be rubbed or knocked sufficiently to produce a mist or fog.

If the oil is brought too rapidly on to the heating surface it is liable to be "cracked" or disintegrated instead of being *vaporized*; it is therefore necessary to warm it gradually.

The necessity for warming the oil and air causes the introduction of a complication absent when petrol is used. A lamp or other source of heat, often the hot exhaust gases, which however are only available after the engine has been started, must be employed. (*Fig.* 3, *Plate* III.).

If the oil is not thoroughly mixed with the air, or if it is allowed to condense before reaching the combustion chamber, imperfect combustion will be the result.

Imperfect combustion means dirty exhaust, smell, choking of ignition plugs and valves, and generally unsatisfactory running of the engine.

(2). *The Admission of the Carburetted Air into the Cylinder.*

Before reaching the valve by which the carburetted air is finally admitted into the cylinder, it is now the most usual practice in modern cars to introduce some form of check or throttle by which the amount admitted at each suction stroke of the piston can be regulated. The introduction of this throttle (*Fig.* 3, *Plate* III.), which was not fitted to the earlier forms of petroleum motors, allows a much nicer degree of adjustment to be obtained of the power of each explosion, and consequently the motor can be controlled to run fast or slow, as may be desired.

The valve by which the carburetted air is admitted to the cylinder is almost universally a mushroom valve and until recently was nearly always opened by the suction of the piston on its forward suction stroke acting against a spring. This system, or the automatically operated valve system, is still in very common use; but one or two manufacturers have for some years used a mechanically operated valve, or one which is positively opened by a cam driven by the engine and is closed by a spring.

The Daimler Company of Canndstadt and the Lanchester Company of Birmingham are two of the companies who have throughout used this form of valve for their larger powered motors, and during the last few months many of the leading French firms have copied their example.

The following advantages are claimed for mechanically operated valves :—

(*a*). That the valves can be opened exactly at the right moment, no matter what the piston speed be.

(*b*). That they are at once opened to their full extent.

(*c*). That it is possible to use a strong spring to close them, thus causing them to shut quickly and remain firmly on the valve seats.

(*d*). That when the motor is running slowly the valves are still opened wide, and the slow-moving piston draws the gas into the cylinder as easily as if it be moving at a great pace ; whereas, if the valve requires to be opened by the suction of the piston, it will be sluggish in its action if the piston be moving slowly and, consequently, the gas admitted will not be sufficient to fire at the end of the next compression stroke. Thus the mechanically operated valves allow the engine to be run more slowly than the automatically operated valves. This is undoubtedly the case, but it is quite a point whether the extra complication is worth the advantage gained.

Personally I am inclined to think it is, and I expect to find more vehicles using the mechanically operated valves in future years.

(3). *The Ignition of the Carburetted and Compressed Air.*

This is a most important part of the details of a motor vehicle.

Generally speaking three systems of ignition are, or have been, used :—

(*a*). The Tube ignition.

(*b*). High Tension—electric with batteries.

(*c*). Low Tension—electric with Magneto or Dynamo.

Of these, (*a*) is mentioned simply in order that it may be avoided. In this system a platinum tube, closed at its outer end, was fitted through the wall of the cylinder in such a way that the gases in the combustion chamber could be forced into it on the compression stroke. The tube was heated by a flame (generally a petrol lamp) from the outside and kept at a nearly white heat. When the gases in the combustion chamber were compressed sufficiently the heat of this tube would cause them to be fired and so expanded.

The great objection to this system is that it introduces a source of danger from fire into the vehicle, which, when such a very inflammable fuel as petrol is employed, is a danger which should be avoided if it is possible to do so.

(*b*). Ignition by batteries, high-tension coil, trembler and sparking plug.

This is perhaps at the present day the most popular form of ignition, and it is certainly very reliable if care be taken to occasionally clean the plugs and see that the batteries are not allowed to run down.

(*c*). The dynamo or magneto system (*Fig.* 1, *Plate* IV.) is coming rapidly into favour, as by it a "fatter" and better spark is obtained, and the low tension connections are not liable to leak and therefore do not require so much insulation as the high tension system.

I have stated that for reasons of safety I object to the tube ignition system in a petrol motor, but a comparison of the electric and tube systems shows the advantage of electric ignition in other respects.

Its starting is instantaneous, whereas a tube takes time to heat up. It can also be so adjusted as to make it impossible for an adverse explosion to be produced before the piston finishes its compression stroke. Extinction is also instantaneous; and there is also surer ignition, as the spark is produced well inside the mixture.

Even if the compression is slight still the charge is fired, and consequently the motor can be run at slow speed; whereas with burners, if the compression is so slight as not to bring the new gases into contact with the tube, running is impossible.

With electric ignition also it is possible for the moment of ignition to be altered when desirable to suit different conditions. Transmission of the combustion in the carburetted mixture is not instantaneous. If ignition occurs at the moment when the piston is at the extreme point of its compression stroke, combustion, when the mixture is rich, has not time to be completed during the working stroke and the total expansive power of the mixture is not obtained for useful work.

It is better, then, for ignition to take place a little before the end of the compression stroke and, if the piston is moving very rapidly, to even still further advance the moment of ignition; but it should never be advanced so much that the firing of the charge begins before the commencement of the second half of the compression stroke.

(4). *The Cooling of the Cylinder.*

The temperature of the charge during explosion is very great. It is estimated at not less than 2,000° C. Without some system of cooling the cylinder it would be impossible to ensure lubrication; and very great and unequal degrees of expansion in the carefully adjusted parts of the cylinder and piston would arise and would impede working. Wedging of the piston and seizing of the connecting rod might be feared, and the valves, especially the exhaust valves, would be put out of working order.

To avoid all this, some system of cooling is necessary; but, as the necessity for this cooling is a source of considerable waste of energy, by wasting the heat units of the fuel, this necessity constitutes one of the grave defects in internal combustion motors. This cooling is generally accomplished by passing a current of water round the combustion chamber and valves, or in some cases round the whole of the cylinders. In some motors it is effected by drawing a current of air over the cylinder by means of a fan as in the Lanchester engine, but as a rule water is used. When water is used it is caused to circulate either by a pump or by gravitation, the former being the more common practice.

In both of these systems the water is passed through a number of pipes usually fitted with some form of gill attachment to help radiation. A year ago nearly all forms of motor vehicles depended, for cooling their circulating water, upon radiation into the surrounding air unaided by any special mechanical means. But latterly the Canndstadt Daimler system has been extensively copied, which consists of drawing air, by means of a mechanically driven fan, in between a number of very thin tubes of various shapes, through which the water is caused to circulate by means of a pump.

This system has the advantage of being very compact, of requiring a much smaller amount of water than the natural radiation system, and of being effective whether the vehicle be at rest or moving along a road. This latter point is one which makes this system almost an essential for any large motor-driven transport vehicle or lorry, and is one which we may expect to find in any such vehicle used for Military purposes.

It is well therefore that we should fully appreciate its disadvantages, which are (*a*) the introduction into an already somewhat intricate piece of machinery of a further complication, *i.e.*, the fan and its driving gear, and (*b*) the fact that the driving of this fan absorbs quite an appreciable amount of work. Mr. Worby Beaumont, in his able work on "Motor Vehicles and Motors," calculates that, to cool a 5½ H.P. motor by fan draught, 1·7 effective H.P. is required, and he consequently unhesitatingly condemns the system as most wasteful and very unsatisfactory.

However this may be, it is, as I have said, the fashionable system of to-day, even in the most rapid and most powerful racing machines; and in my opinion it is absolutely essential for slow-moving military lorries.

The pump used for circulating this water is driven in two ways, either by a friction drive off the fly-wheel of the motor or by gearing. The latter in my opinion is the better and the more reliable, and will, I anticipate, be universally adopted in a few years.

One word of caution must be given here where any form of water cooling is used. In frosty weather, or in even possibly frosty weather, should the motor be liable to cool down, as when standing at night in a stable, the circulating water must be all drawn off, or there will be danger of its freezing, in which case water jackets or cylinders may be cracked or the pump broken on starting.

(5). *Methods of Dealing with the Exhaust Gases.*

The escape of the products of the explosion is assured by a valve worked by levers and a cam fixed on a shaft connected with the motor shaft by a system of toothed gears which make the cam shaft rotate once whilst the motor shaft rotates twice; thus the exhaust valve opens once during every two revolutions of the motor.

This valve is arranged to open a little before the piston reaches the forward end of the cylinder on the explosion stroke, so that there is a little lead in the exhaust. This lead, although it allows a slight amount of the pressure of the gases to be lost, augments the piston force by preventing an otherwise considerable counter-pressure from arresting the impetus of the piston during its return stroke, and allows the exhaust to be quite complete before the following suction stroke begins.

The springs which press the exhaust valves against their seats must be strong enough to prevent the valves being lifted during the suction stroke.

The exhaust gases are discharged through the exhaust valves at considerable pressure, and, if admitted at once into the air, would make a considerable noise. To decrease this noise the burnt gases, on leaving the cylinder, are conveyed to an exhaust box or silencer in which the gases expand gradually and reach the air through a number of small holes. The larger the silencer and the smaller and more numerous the perforations, the better will the noise be deadened.

In some silencers the exhaust gases are allowed to find their way to the outer air through pebbles packed in a cylindrical box.

(6). *Control of the Motor.*

In speaking of the admission of the gases into the cylinder, mention was made of the throttle; this throttle (*Fig.* 3, *Plate* III.) may be actuated by a governor or by levers, and frequently by both.

In some cases, as in the Wolseley standard engines, no governor is fitted, and the engine is controlled entirely by throttle valves actuated by hand and foot; but in most cases there is a governor. This governor, in most of the very latest designs of engines, acts upon the throttle valves; but many engines still exist where the governor acts upon the exhaust.

The Daimler system, used in the English Daimler and in the Panhard engines, is on this principle. Here the cam actuates the exhaust valve by means of a tongue which normally hits the bottom of the exhaust valve spindle at the proper time and so lifts the valve. When, however, the speed of the engine causes the governor balls to fly out, the bottom of the valve spindle is pressed forward and the tongue misses it.

As the exhaust valves, being thus prevented from lifting the burnt gases, are retained in the cylinder during the scavenging stroke, no fresh gases can be drawn in during the following suction stroke; and a cycle is performed without any fresh explosion. This is repeated until the speed of the engine is so reduced that the governor allows the exhaust valves again to open and the burnt gases to be carried off.

Other governors act on the inlet valves, preventing them from opening, as in the Lanchester (*Plate* IV.).

(7). *Lubrication.*

Lubrication in any machinery is of the greatest importance; but in an internal combustion motor the problem is complicated by the great heat which is developed in the combustion chamber by the explosion of the driving gases and by the great piston speed to be provided for.

The essential properties required for the lubricant employed for motor cylinders may be stated as follows :—

(*a*). The oil must not be liable to decomposition at working temperatures.

(*b*). If of mineral origin, it must not volatilize to any considerable extent, nor emit offensive fumes at working temperatures, nor produce carbonaceous deposits in cylinders or valves.

(*c*). At working temperatures it should retain sufficient body to ensure the presence of an effective film of oil between the piston and the walls of the cylinder.

(*d*). It must be sufficiently fluid at normal temperatures to permit of its easy introduction to the cylinder or crank chamber by ordinary appliances.

For these purposes a mineral oil of the Petroleum group, having a specific gravity of from 890 to 910 and an open flash point of between 500° and 550° Fahrenheit, is found to be the most effective.

Whilst it is essential that the pistons of an automobile should have sufficient lubrication, yet it is also necessary for their proper use that excess of lubrication be avoided.

Excess of lubricant is injurious because it disturbs the composition of the carburetted mixture and deprives the explosion of part of its force.

Lubrication of the motor may be carried out either by application of the oil by pressure or gravity to the portions requiring it, or by the more common but much rougher method of "splash lubrication."

This latter system, applicable only in a vertical motor, consists of simply half filling the crank chamber with oil and letting the cranks as they dip into it splash it up into the cylinders and on to the half-speed shaft and valve cams. This is a ready and popular method, but it is rough and crude. It is likely to lead to over lubrication and its accompanying disadvantages, which, though objectionable, are not nearly so disastrous as under lubrication.

A great motor car racer, in discussing this point with me the other day, said that he would have no other form of lubrication for his racing car motor than the splash system, "for we must have something simple and effective which requires a minimum of attention. All we need to do during a race is every now and then to pump oil into the chamber till the exhaust stinks a bit and emits blue smoke, and then we know we're all right."

For Military work this may be also a suitable system, as sometimes rough and ready methods are better than more complicated though more accurate ones; but it must be remembered that when my friend's motor emitted blue smoke and made itself otherwise objectionable he was losing power, risking the sooting of his valves and endangering his ignition.

Electric Motors.

I have been asked to compare oil engines for motor vehicles with electrically driven vehicles from an economic point of view.

The comparison is difficult, almost impossible, as the two classes of vehicles are so different in their capabilities, power, speed, and range of action.

The purely electric vehicle, putting aside such "freaks" as the Baker Torpedo, has so far been only made in one class, namely the town carriage; whereas the internal combustion engine is used to propel vehicles from the bicycle to a 5-ton lorry.

The electric carriage has, normally, a range of some 30 to 40 miles, although some have been built with enormous batteries (weighing alone over one ton) to travel over 150 miles on one charge.

The speed of the electric vehicles is also very limited, except for short sprints where the life of the batteries is not a matter of great moment.

In fact the electric carriage is, as yet, not a practical vehicle except for town work. The wear of the batteries alone is a very serious item; as an idea of the cost I can say that the two big electric carriage companies in London charge over £200 a year to house, clean, re-charge, and keep in order an electric brougham.

Generally speaking then, an electric carriage may be considered an expensive luxury, though luxury I admit it to be.

As to the cost of the internal combustion vehicle, much depends upon what is required. A high speed car with pneumatic tyres will cost 6d. or more per mile; a 6 H.P. 1-ton delivery van, travelling at about 9 miles per hour, has been found to cost 1·44 pence per useful ton-mile.

In speaking of electric vehicles, I have considered those which are purely electric.

Mixed System Motors.

Several mixed systems are being tried, some of which have given good results.

In all of these the prime mover is a petrol engine. The Lornher Posche system generates electricity by driving a dynamo with a petrol engine, and communicates the energy to the road wheels by means of electric motors.

The Fischer system has, in addition to the above, a secondary battery which is charged by the dynamo when the latter does not require all its possible output to drive the vehicle and reinforces the dynamo when the drive is heavy.

In the Mensom system a petrol engine normally drives the car in the ordinary way, but also drives a dynamo which in its turn charges accumulators when the petrol engine has any power to spare. When, however, the car demands more than the engine can give, the battery drives the dynamo as a motor and the dynamo assists the engine.

I do not think that for Military purposes, or even for general commercial use, we are likely to see the adoption of any system requiring secondary batteries, unless some greatly improved battery is invented. Such batteries are frequently spoken of, but are as yet unobtainable.

For the immediate future, therefore, I am inclined to think that our vehicles, whether for passengers or goods, will be propelled by that valuable and interesting motor the Internal Combustion Engine.

Works Consulted.

"The Automobile" (Lavergne); "Motor Vehicles and Motors" (W. Worbey Beaumont); "The Autocar;" "Automotor Journal"; "Motor Car Journal"; "Descriptive Manual of The Lanchester Motor Carriage."

Note.—*Plates* V. to VIII. show types of automobiles in use for Military purposes.

PAPER IV.

CONSTRUCTION OF THE CONNAUGHT BRIDGE ACROSS THE SWAT RIVER AT CHAKDARA, N.W. FRONTIER, INDIA.

By Capt. H. BIDDULPH, R.E., *late Garrison Engineer, Chakdara.*

LIST OF PLATES.

CONSTRUCTION OF THE CHAKDARA BRIDGE.

THE main road to Chitral crosses the Swat River at Chakdara, some 10 miles north of Malakand. This road was opened up by the Chitral Relief Force in the expedition of 1895; at that time a crib and trestle bridge for foot and pack traffic was first constructed over the river; and this was subsequently replaced, during the field operations, by a suspension bridge with built-up iron frames on stone piers on a different alignment. A full account of both these bridges was given in the *R.E. Professional Papers*, 1896. Old Bridges.

Owing to the conditions under which the suspension bridge was constructed, it was impossible to get in anything but very shallow foundations for the necessary piers. Additional protective works were carried out later on at more leisure; but, in the hot weather of 1899, an exceptionally high flood very nearly wrecked the bridge by scouring out the foundation of one of the main piers; and the same thing nearly occurred to another main pier in 1900. The maintenance of the bridge during the annual hot weather floods proved to be most costly, and it needed unremitting attention.

Figs. 1 and 2, *Plate* I., give two sections of the river bed taken at the site of the suspension bridge in October, 1899 and August, 1900; and show the varying scour of the river, which takes place almost entirely during the floods, when the river comes down with very great violence.

In consequence, it was finally decided to build an entirely new bridge of a permanent character. Its site was fixed by the position of Chakdara Fort which commands the crossing of the river; and it was therefore to be parallel to the old one, and 100 feet distant from it, on the down-stream side. New Bridge.

General Description.

It was at first decided to construct a road bridge for wheeled traffic, 9 feet wide, in three spans of 250 feet each; but, owing to the construction of the railway (2 foot 6-inch gauge) from Nowshera to Dargai, this decision was altered at the last moment, and orders were given for the construction of a bridge capable of carrying a 2-foot 6-inch railway in addition to a road with a width of way of 15 feet. Five spans of 160 feet each were substituted for three of 250 feet (*Fig.* 3, *Plate* I.).

The Swat River at Chakdara runs through a valley about two miles wide, with a range of hills on each side; in the cold weather it runs in different channels with islands in between (*Plate* II.); and it is only in the highest hot-weather floods that some of these islands are covered with water. The bed of the river consists of shingle, water-worn stones and boulders mixed with sand; the valley is covered with alluvial soil of varying thickness on which the Swatis grow rice.

Before the alteration in width of roadway and number of spans had been ordered, iron curbs for the four piers of the road-bridge had been purchased. These were naturally of unsuitable size for the piers of the combined rail and road bridge, which was 6 feet wider; but eventually some of them were altered and used.

Method of Sinking Piers.

It was of course seen that the chief difficulty lay in getting in the piers to a proper depth. Owing to the nature of the river bed dredging was out of the question; while sinking the wells by means of air locks would be both slow and extremely costly.

The method decided on was as follows:—At the site of the bridge the river flowed in three main channels (*Plate* II.). By means of bunds it would be possible to divert the river to either bank, leaving one or two channels dry; the excavation of the piers could then be carried out by hand, the influx of water into the wells being controlled by steam pumping; the pumps would be aided by a tail-race, which would partially drain the foundations in addition to keeping within practical limits the height to which water would have to be pumped. Owing to the positions of the islands and channels it was decided that the piers should be constructed from the north (or Chakdara) bank towards the south (or Malakand) side. From this Plate it can be seen that the north channel could be closed with little labour, and thus work could be at once started on three piers; whereas it would be a very lengthy matter to close the south channel (*Plate* IV.).

New pumping machinery had been purchased in India, the chief items of which were four portable steam engines (8 and 10 N.H.P.), two 6-inch centrifugal pumps (a third was afterwards purchased), and two No. 8 pulsometers together with accessories and much other minor plant necessary for the work.

Commencement of Work.

Work commenced on 12th September, 1901, by ferrying the machinery, etc., to the big island near the site of the work; this was effected by means of two large country boats running on a steel cable, in somewhat the same manner as a flying bridge; while for the transport of the steam engines the two boats were formed into a raft.

Diversion Works, 1901.

A few days later, work was commenced on diverting the north stream of the river. The positions of the bunds and tail-race constructed in 1901 are shown on *Plate* II. The method of diverting the river was as follows:—Bunds were made in pairs; first of all a bund of boulders and coarse grass was built at an angle of about 30° with the stream; this broke the force of the current, and enabled a second more or less water-tight earth bund to be constructed behind, and parallel to, the first. Between each pair of bunds a clear water way and drain was left, to relieve the earth bund of unnecessary pressure. Advantage was taken of any natural islands and channels in the river, and additional cuts and channels were made where necessary. Work on the bunds was begun at the site of the bridge and carried on up stream, the different channels being diverted one by one, beginning down stream near the bridge and ending up stream on the opposite bank; but each individual bund was constructed with the current, as this was the easiest method (*Plate* IV.). The bunds were made so as to have a width of 4 to 6 feet at the top; the side slopes of the boulder bunds were left at their natural angle of repose, and those of the earth bunds at $\frac{1}{2}$ to $\frac{1}{3}$.

From *Plate* II. it will be seen that the bunds constructed during September and November, 1901, exposed the sites of the north abutment and the next three piers. The only danger of thus restricting the water way lay in floods consequent on rain up the valley; and there was no means of getting timely notice of a coming flood, Upper Swat being a closed country. The first bunds constructed were very nearly breached on 4th October, 1901, in this manner.

Work on the north abutment commenced on 7th October, 1901, and that on the next two piers soon followed. The tail-race (*Plate* II.) was a very heavy piece of excavation, which went on concurrently with work on the piers during this season. Its total length was about 1,200 yards; the flattest slope being about $\frac{1}{750}$; R.L. at its down-stream end 2213, and at its commencement 2220.

Work on the tail-race was most laborious, the excavation being entirely among boulders; bed rock was struck in one place, when it was approaching completion. The ground level of the first three wells was 2236·5.

Construction of Piers.

Night work on the piers was started on 31st October, 1901, the gangs being divided into three shifts of eight hours each; and this practice was followed for the future on all sinking work, whenever practicable. Wells' flare lights were used at first, but were soon discontinued on account of the heavy expenditure of oil. They were replaced by ordinary hurricane lamps burning kerosene and native torches burning mustard oil; these answered quite well for all practical purposes.

The general method of sinking the foundations was as follows:—Excavation was done by hand to a depth of 16 to 20 feet and then a timber lining was fitted into the shaft of the well. This timber lining was composed of vertical deodar uprights, 6″ × 9″, about 6 feet apart, strongly braced by horizontal rings of timber struts, on much the same principle as the centering of an arch; a large polygonal hole being thus left in the centre, to give room for the pumps and men to work in. Behind the timber uprights stout planks were fitted in and secured. The excavation was proceeded with, and a second, but shorter, section of timber lining, only a few feet deep, was fitted underneath the first one; and then a third underneath the second one, until the full depth had been excavated. This method was altered and improved later on (*Plate* X.).

The centrifugal pumps were carried on a platform of wooden trussed beams, 34 feet long, thrown across the well's mouth; and, when it was necessary to lower them, in order to decrease the lift and to bring their delivery pipes down to the level of the bottom of the cut connecting the well with the tail-race, they were carried on a small platform of trussed beams, 14 feet long, which was suspended bodily inside the well from the long trussed beams above by iron rods 9 feet long. The pulsometer pumps were slung by Weston blocks, with specially long chains, from gyns formed of light wrought-iron piping with screwed joints.

On 28th November, 1901, work was stopped on No. 3 Well, as the pumps had to be concentrated on Nos. 1 and 2 Wells.

On 1st December work on No. 2 Well was stopped owing to the pumps at work there being unable to cope with the heavy influx of water, and work was concentrated on No. 1 Well (the north abutment), in which a very hard clay had been reached at R.L. 2206. Water-bearing sand was struck in the centre of the well at R.L. 2201; and this hole was carefully plugged with small bags of P.C. concrete. Excavation was carried down 5 feet into the clay and the foundations of the abutment then laid. In the first four wells this was generally done by first laying down two or more layers of well-tarred gunny bags (of 2 cubic feet each) filled with P.C. concrete. On the top of these bags P.C. concrete was laid and consolidated, holes being left for the suction pipes of the pumps, and the stone masonry steining was then built in cement. Great care was always exercised in the pumping to prevent loss of cement, the water level being kept below the top of the tarred bags until the concrete above had firmly set. Foundations of No. 1 Well.

On the 16th December work was re-commenced on No. 2 Well, in which the foundations had been sunk from R.L. 2236 to 2213. A very large influx of water had to be dealt with, all four pumps being in constant use; a fifth pump (6-inch centrifugal) was procured, and put into use on 20th December. Foundations of No. 2 Well.

The work went on slowly owing to the difficulties caused by the enormous inrush of water from springs 30 feet or more below the ground, by means of which hundreds of small fish, the biggest about 6 inches long, had found their way into the well. Every device was used to increase the efficiency of the pumps, by lowering the pumps into the well as far as possible, etc.; and on 1st January, 1902, excavation had been carried down 35 feet to R.L. 2201, *i.e.*, to within 1 foot of the depth (R.L. 2200) at which it had been decided to lay the founds of this pier.

Very serious difficulties had, however, been met with; the enormous inrush of water, at the points where the springs burst into the well, washed away the sand between the boulders at these points, rendering them very unstable and bringing enormous and unequal pressures to bear upon the timber lining of the well. This created a tendency for some of the heavy vertical timbers to settle, thus distorting the struts out of the horizontal. A careful watch was kept, many fresh struts being fixed and the old ones re-fitted as the distortion occurred.

During the night of January 1st—2nd a very serious settlement took place in two of the vertical timbers, and the mistri (foreman) in charge of the night work neither reported it nor stopped the work, but awaited the arrival of a superior native subordinate on the scene. He then reported it; and scarcely had an examination been begun when a portion of the timber shaft failed and an avalanche of stones and boulders fell, overwhelming two coolies of the gang at work inside the well and putting the three centrifugal pumps out of action. The two pulsometers alone remained working; but the water instantaneously flooded out the well, as the rate of ingress was 125,000 gallons per hour or more. All five suction pipes were buried many feet deep in *débris*.

The first thing to be done was to clear away as much spoil as possible from round the well, and to recover the three centrifugal pumps and such piping as was possible. About one half of the perimeter of the timber shaft remained intact, the other half was either broken or hopelessly distorted. Fortunately there happened to be at hand one spare 6-inch, and two odd 5-inch, foot-valves; these latter were fitted to two of the centrifugal pumps by means of specially made reducing tail-pieces; and on 8th January the three centrifugal pumps were again at work. In this way the water was controlled to a certain depth, and much of the spoil and wreckage removed from the well.

On 10th January new timbering was commenced in the well, the diameter of which had been much enlarged by the slip. As has been stated above, one half of the old timbering remained intact, and the new work consisted in carefully extracting the damaged timbering and pinning new timbers on to the undamaged half. All cavities behind the planking were carefully filled with bags stuffed with grass. As the work progressed the pumps were lowered into the well on a hanging platform, and by the 18th January work had been carried down to R.L. 2206; three centrifugal pumps and one pulsometer were then working, but two of the former had only the 5-inch foot-valves attached. On the 19th January one of the dead bodies was recovered, and also the foot-valve and sliding suction pipe of one centrifugal pump. On the next day the remaining valves and pipes were extracted, and on the 21st the other body was recovered. In both cases, although decomposition had set in, the state of the bodies was not nearly so bad as might have been expected after a period of nearly three weeks. The cost of this disaster was about Rs.5,000. By the 22nd the excavation had been carried down to just below R.L. 2201, and it was determined to lay the foundations at this level. No clay had been struck, the strata consisting entirely of water-worn boulders and stones mixed with sharp coarse sand.

It may here be stated that only in the north abutment were any clay strata found; the size of the boulders varied up to a maximum of 5 feet length and $1\frac{1}{4}$ tons weight.

The foundations were laid, in the same way as No. 1, on 23rd January; and the stone masonry steining rapidly built in cement up to the level of the tail-race. In all cases the timbering was removed piecemeal as far as possible, while the masonry was in progress, to save expense. The interior filling of the wells was as shown in *Plates* VI.; and generally consisted of first a plug of P.C. concrete, some 6 to 8 feet thick, and then dry filling with layers of P.C. concrete, 2 feet thick, at intervals. On all the piers cut-waters were corbelled out on both sides; whereas the abutments were built up straight (*Plates* VI. to IX.).

On 31st January, 1902, work began again on No. 3 Well, and a start was made on No. 4 (*Plate* VII.). In No. 3 Well all the vertical deodar uprights of the timber shaft were braced to each other on either side by $\frac{3}{4}$-inch iron rods; heavy cross beams were put in horizontally along the diameters of the well, in addition to the system of strutting described before; and all cavities behind the planking were carefully filled with bags stuffed with grass. No. 3 Well, like No. 2, gave a lot of trouble; the influx of water from springs was enormous, equalling that of No. 2; and in addition the soil was very unstable.

Foundations of No. 3 Well.

On 11th February work was stopped on No. 4 Well, and all the pumping machinery concentrated on No. 3. On 13th February No. 3 had been sunk to R.L. 2201·5; and then the difficulties increased still more. Owing to the violent inrush of water at foundation level it was impossible to put in any fresh timbering below the existing shaft; for, directly a small excavation was made, the water washed in fresh material from behind. The following method was therefore employed:—Excavation was made down to foundation level (R.L. 2200·25 approx.) for one bag of P.C. concrete at a time, which was laid immediately the hole for it was ready; then in a similar way another bag was laid touching, and alongside of, the first; and so on until the bottom of the well had been covered with bags of P.C. concrete laid at the required level. This took some time to do as progress was necessarily slow; and a good deal of careful carpenter's work was necessary when the bags were being laid on the outside perimeter near the timbering, to prevent any settlement of the latter. It took from 3 p.m. on the 15th September to the late afternoon of the 18th to lay all the bags properly.

The foundations had been levelled up with two or three layers of concrete bags when a fresh difficulty took place. Only a little of the water rushing in from the sides of the well could pass between the bags to the pumps in the centre of the well; the rest of it, being impeded by the bags, washed over the top of them in a very heavy flow, which would have been quite fatal to the laying of any concrete. To cope with this, the bottom of the well was divided into quarters by planks, 1 foot wide, laid vertically on their long sides; and tarpaulins were then nailed inside them; the concrete was laid and consolidated very satisfactorily inside these waterproof compartments, as the water forced its way through small drainage passages between the planks to the pumps; more concrete was then laid in one piece over the whole lot. The masonry steining was built up as before.

Foundations of No. 4 Well.

Work re-commenced on No. 4 Well on 25th February. This well was situated scarcely 100 feet distant from the complete volume of the river, from which it was separated by a bund; and its position was in the centre of a main channel, in a pot-hole in the river bed. Contrary to all expectation the yield of water in this well was comparatively insignificant, being less than that in the north abutment. Work was carried on in much the same way as before; but the timber shaft was still further strengthened by fixing distance pieces of $1\frac{3}{4}$-inch angle iron at the heads and feet of all the deodar uprights, between each adjacent pair. Each vertical timber was also connected by an angle-iron strap with the one immediately below it. (*Fig.* 3, *Plate* X.). The heavy cross beams and $\frac{3}{4}$-inch bracing rods were used as before, in addition to the usual timber struts; and this method was alwaps adopted in the future.

The Director-General of Military Works inspected the work on 13th February, 1902, just before the foundations were laid in No. 3 Well; and gave orders that an attempt was to be made to try and get in all six wells that season. This would involve levelling the existing bunds, diverting the whole river back again to the north bank by a new system of bunds, and the excavation of such new tail-race as might be necessary. To accomplish all this the time was now very short; for not much of the new work could be done before the 4th well had been sunk and the masonry brought up to above water level. Such work however as was possible in this direction was commenced in the last week of February, pieces of the new bunds being constructed and diversion channels opened up. As No. 4 Well was situated in one of the main channels of the river (the ground level being R.L. 2227·5), it was resolved if possible to carry the foundations down deeper than in the case of Nos. 1 to 3. In the meantime the weather had become a little unsettled, and the river had risen 10 inches; on the 18th March, 1902, heavy rain fell, and the river rose more than 4 feet higher by 1 p.m., making a total rise of 5 feet. This heavy flood tried the bunds very severely, and continuous work during the day was necessary to preserve them; in addition such work as had already been done on the new system of bunds had to be demolished. The next day the foundations were laid in No. 4 Well at R.L. 2197.

On 22nd March a commencement was made with blocking the tail-race between Nos. 2 and 4 Wells; the water from No. 4 being pumped directly into the main river over the bund (*No.* 5, *Plate* II.).

By the 26th, nearly all the diversion bunds were dismantled, and progress made on the new bunds for diverting the river to the north bank. The tail-race soon opened out into a big water channel 100 feet wide, and proved of great use in relieving the two northern channels of the river bed.

On the afternoon of the 27th a sudden hailstorm of excessive violence burst in the direction of Uch. Within a few minutes the northern channel of the river rose $4\frac{1}{2}$ feet, coming down in flood, covered with masses of floating hail and ice. This instantaneous rise precluded the possibility of any preventive works; and the flood water, entering the tail-race, topped the cross bunds and drowned out the site of No. 4 Well.

As before stated the site of this well was in the centre of the main central channel of the river, in a hole. On the down-stream side it was protected by a small bund (*No.* 5, *Plate* II.) to prevent the river flowing back into it; and now a smooth lake existed on the spot where No. 4 Well had been, only the smoke stacks of the four steam engines remaining visible above the surface.. The first thing to do was to heighten the cross bunds in the tail-race to prevent any further ingress of water, to drain the site as much as possible, and to make preparations for extracting the pumping machinery. An 18-foot derrick was rigged up in front of one of the engines, and a 14-foot shears in rear of it; separate blocks and tackle were fitted from these to chains carefully secured by divers to the engine; the blocks and tackle of the shears were worked by a 10-ton crab fitted up in rear, while those of the derrick were worked by hand. In this way either the fore-carriage or the fire-box end of the engine could be lifted, and the whole engine also pulled bodily backwards. This engine was extracted by the afternoon of 29th; after cleaning, etc., pumping re-commenced on the early morning of 31st and the masonry of the well was exposed that evening. Very little damage had been done, and the masonry of this pier was rapidly completed without further mishap.

Diversion Works, Spring, 1902.

On 26th March work had been begun on No. 6 Well (the south abutment), as the site of it at this time was above water level. *Plate* III. shows the number and position of the second set of bunds that was constructed during the Spring of 1902 in order to divert the river back to the north bank; this system was not completed, and the southern channel (in which the site of No. 5 Well lay) was never diverted, as the lateness of the season and the approaching summer floods finally rendered this impossible. On the 2nd April a commencement was made of ferrying engines and stores back to the site of No. 6 Well. Work on the new bunds was going on incessantly; but they were constantly being breached by floods, and it was also quite obvious that the north channel alone would be incapable of now conveying the whole of the river water; in fact it was becoming evident that all that could be done during the remainder of this season was to try and keep down the height of the water in the southern channel by means of the bunds already completed, and so (if possible) finish off No. 6 Well.

Foundations of No. 6 Well.

The ground level at this well was R.L. 2233; and by 18th April the shaft had been lined with timber (strongly braced with iron in the same way as No. 4) down to level 2216. The soil in this well was rather different to that in the others, and gave difficulties of its own. There was a very much larger quantity of sand mixed with the boulders than had hitherto been the case; and this made it correspondingly difficult to sink the foundations in the method previously employed. On the 19th it was decided to construct and put in a special curb, and to carry on the sinking by means of that. One of the iron curbs previously mentioned (page 102) was utilized for this purpose. These curbs were 6 feet high, with a width of 3 feet 6 inches at the top, cutting edge of 30°, extreme diameter $14' \times 16'$, with semi-circular ends of 7 feet radius, weight $7\frac{1}{2}$ tons. In order to lighten the weight, and to increase the space available for the pumps and men to work in, one of these curbs was cut in two horizontally through drum-plate, cone-plate and gussets; lengthening pieces, 4 feet long with extra gussets, were inserted in the middle of each side, and the palm rods refitted. The new curb was 2 feet 10 inches high, 16 inches wide at the top, extreme diameters 14′ × 20′, with semi-circular ends of 7 feet radius, weight about 4 tons (*Plate* IX.). It took nine days to construct this curb, as all the cutting had to be done by hand-ratchets; and before that time the well had been timbered down to R.L. 2213 and work suspended. The river too was constantly rising and the weather was very unsettled.

On 29th and 30th April the curb was lowered into the well in six pieces (on account of the timber struts it could not be lowered in one piece), and riveted and bolted together at the bottom; bolts being used for the exterior joints and places where riveting was impossible. Sinking commenced on 1st May. In the meantime special stone for the steining was being prepared, carefully cut, and chiselled smooth on the outside; the masonry rings being corbelled out inwards from 16 inches to 24 inches thick at 2 inches per foot, in order to give additional strength.

On 3rd May R.L. 2210 had been reached, and the first $4\frac{1}{2}$ feet height of masonry steining was built in cement (1 to 2). All this time the river had been steadily rising, and the bunds were undergoing constant repairs. On 6th May the river had risen to such a height that it began entering the well for the second time; and it was evident that work could no longer be carried on except at useless expense. R.L. 2208 had been reached. A temporary fall of a few inches in the height of the water in the southern channel rendered it possible for the steining to be completed to a height of 10 feet, and for the necessary preparations to be made to secure the work already done from damage by the summer floods.

If possible the bunds already constructed were to be preserved during the floods; and in the meantime preparations made for getting all the necessary plant and stores ready for erecting the girders, the first span of which was due at Nowshera in July. The work to be done during the next few months consisted of:—

(*a*). Making up the staging and a travelling gantry for the erection of the girders.

(*b*). Building up the masonry of the north abutment and next three piers.

(*c*). Quarrying bed stones.

(*d*). Making riveting tools.

(*e*). Making up a special curb for use on No. 5 Well, should it be necessary, like that made for No. 6.

(*f*). Making arrangements for the transport of the component parts of the girders by road from Nowshera.

Staging for Erection of Girders.

The following arrangements, which had been commenced beforehand, were made for the staging for the erection work. Staging was required for one span, 150 feet long, 25 feet wide and 20 feet high (in two tiers of 12 feet and 8 feet). A certain amount of old Sullivan's staging in odd pieces had been purchased from the Railway Department, and what was now necessary was to complete this; for this purpose about 1,000 running feet of Oregon pitch-pine, $12'' \times 12''$, in 25 and 50-foot lengths were procured from Calcutta; some 4,000 running feet of second-hand 60-lb. rails were bought from Karachi; 40 rolled steel joists, $9'' \times 4'' \times 20'$, were issued from the surplus stock at Dargai Fort; the necessary steel and iron sections were purchased; and 4 tons weight of special castings, necessary for various purposes, were made to order by a firm in Rawal Pindi. The gantry, to travel on the top of the staging, was made of $12'' \times 12''$ pitch-pine and $12'' \times 3\frac{1}{2}''$ steel channels, with an inside clear width of 22 feet and a height of 25 feet; this gave ample clearance on all three sides round the two girders of a span when in position; the wheels were double flanged, actuated by cogs and pinions worked by hand. A 5-ton crab, fitted on the top of the gantry, could be traversed laterally (*Plates* XIII. & XV.). The staging and the gantry were made up at Chakdara.

For the riveting tools, tool steel was purchased in Bombay and made up at site.

Bed Stones.

An attempt was first made to quarry the bed stones, twenty in number, each measuring $4' \times 3\frac{1}{2}' \times 2'$, from the quarry near Chakdara. But it was found very difficult to quarry stones of this size without flaw; and, after two or three had been cut out, the remainder (together with the ornamental corbel stones, 1 foot thick, required to finish off the tops of the piers) were quarried near Hassan-Abdal.

Transport Arrangements.

For the transport of the heavy pieces of girders from Nowshera four drugs were made at Chakdara. The contract of the firm supplying the girders was for delivery at Nowshera station, 57 miles south of Chakdara. Nowshera is connected with Dargai, a distance of 40 miles, by a 2-foot 6-inch railway, which at that time only transported articles within certain lengths and weights, as the Kabul River had to be crossed by a boat ferry. The heaviest portions of the girders were the boom pieces, varying in length from 31 feet 4 inches to 33 feet 6 inches and weighing up to $2\frac{1}{4}$ tons each.

Between Nowshera and Dargai the road is fairly flat; from Dargai it rises over the Malakand Pass, at a ruling gradient of about $\frac{1}{20}$, and it then falls at a somewhat steeper slope into the Swat Valley. The road over the pass has many very sharp turns and re-entrant angles.

At first light pieces were railed to Dargai; but after a time, on account of the Kabul River ferry, it was found to be less troublesome and just as cheap to cart everything by road straight from Nowshera. The carriage contractor also preferred, at the risk of an occasional breakdown, to cart the boom pieces on two-wheeled country carts instead of on the four-wheeled drugs made for the purpose; this was allowed, although the narrow tyres of these country carts did some damage to the road over the pass under such heavy loads.

By the end of August, 1902, the first span of girders had arrived at Chakdara, and all the staging, plant and machinery were complete and ready. The bunds constructed during the spring had long ago been entirely washed away by the floods, and the river was running in its usual channels. Owing to the order in which the piers had been constructed, beginning at the far bank, it was of course necessary to ferry over all the pieces of the girders, etc., as before.

Erection of No. 2 Span.

The first span erected was that between Nos. 2 and 3 Wells, as this interval was dry (except during the occasional high floods) and the men would consequently be able to get accustomed to their work without difficulty (*Fig.* 1, *Plate* XIV.). The general method of erecting all the spans was somewhat similar, and can be here described:—

Owing to the fact, explained above, that the girders would have to be erected beginning at the north bank on the far side, hoisting by a derrick at the pier in question was necessary, as the materials could not be delivered at road level. Tram-lines were therefore laid on the south bank and on the centre island; and by means of these, and the ferry across the river, the materials were delivered at the proper pier. Each piece was then hoisted by a 50-foot derrick (of 12″ × 12″ pitch-pine), and placed on a material trolley running at road level on the top of the staging; the piece was then picked up by the gantry and fitted in position.

Previous to this the centre line of the span had been accurately laid out on the top of the staging with a theodolite, and the bed stones marked for the reception of the bearings. When all the lower boom pieces had been erected and the camber set out, the correct distance of each joint from the centre line was adjusted, and the joints were tightened up and riveted. Next the upper booms, struts, diagonals and cross girders were erected, and the whole span riveted up. The camber-jacks were then let down. The line-bearers and flooring were erected at leisure afterwards. The camber was always set out on a circular arc with $\frac{1}{2}$ inch greater rise at the centre than the camber marked on the drawings; as it is always much lighter work to ease the camber than to raise it, and the camber, moreover, has a tendency to sink. All the joints were brought properly together. Each joint of the lower booms was supported on four screws, working in bottle-nuts fixed in mulberry-wood blocks; these screws were manipulated by wrenches, and afforded an easy means of raising or lowering the joint in setting out the camber. The erection of the first span commenced on the 9th September and the camber-jacks were let down on the 25th.

Erection of No. 1 Span.

The staging was then transferred to the span between Nos. 1 and 2 Wells. This span crossed the north channel in which a heavy current was flowing; a small stone bund was made across the channel a little way up stream, in order to break the current, and the river bottom underneath the span was levelled up with boulders. The staging was then erected on these boulders in shallow water, and the span erected as before. The erection and riveting of this span took twelve days (from 1st to 13th October), and the safety bund above it was then demolished (*Fig.* 3, *Plate* XIV.).

The work now left in hand was to erect the 3rd span between Nos. 3 and 4 Wells, and to go on with the work on Nos. 5 and 6 Wells. To sink No. 5 Well it was of course necessary to divert the river to the north bank. The north channel, though assisted by the tail-race of 1901, which had widened out to 100 feet width, was insufficient to carry all the river water, even in the cold weather. During August, therefore, a wide artificial channel had been excavated through the large island at the centre of the bridge (*Plate* IV.); this would allow of the main centre channel of the river being kept open, in addition to the northern one, when the new system of bunds was completed. It meant, however, that the third and fourth wells would be separated by a deep channel of fast running water, and to avoid delay it was determined to erect this span on piles.

Diversion Works, Autumn, 1902.

Now that the span over the northern channel was completed, work was pressed forward on the bunds for diverting the river to the north bank (*Plate* XII.). As will be seen from *Plate* IV. this system of bunds had to be very extensive, and ran a considerable distance up stream (some 1,300 yards) owing to the configuration of the river.

Completion of No. 6 Well.

Work too was now once more possible on No. 6 Well, the south abutment, and was commenced on 14th October (*Plate* XI.). For the first four days considerable difficulty was experienced in this well from blowing (*i.e.* sand entered the well from the sides as fast as it was removed); this was overcome, and the well then began to sink properly; by the 27th October the curb had reached R.L. 2200, the proper depth. Very little trouble was met with from the water.

The chief difficulties were first from the well blowing, and then from boulders underneath the cutting edge of the curb. The curb was heavily loaded during the sinking operations, and great care was taken to sink it as level as possible in order to reduce to a minimum the cracking of the steining.

The masonry of the well was built up as follows:—First, in order to facilitate pumping and to keep the concrete filling as dry as possible, 3-inch wrought-iron pipes in suitable lengths were laid like the spokes of a wheel from the perimeter of the curb to the suction pipes of the pumps. Then a layer of bags filled with P.C. concrete was laid over the bottom of the well as before; and on the top of these P.C. concrete was put down in layers and consolidated in the ordinary way up to the top of the steining. On this the 3-foot 6-inch steining was then built, and the interior filled as before (*Plate* IX.).

On 31st October, 1902, the bunds were approaching completion when there came a heavy flood, due to rain, which broke many of the bunds and did considerable damage. By the 9th November this damage had been made good, and the bunds were practically completed.

Foundations of No. 5 Well.

Work on No. 5 Well was commenced on the 11th November. To aid its construction, and to carry off water that cropped up in the bed of the river between the bunds and the well, a small tail-race was also taken in hand (*Plate* IV.). Work on this well progressed very satisfactorily, R.L. 2215 was soon reached, and the shaft properly lined with timber. The special curb (*Plate* VIII.), which had been made during the hot weather, was then put in, in the same way as in No. 6, and sinking carried on in the usual manner. No difficulty was met with from the water, the yield being uncommonly small. The well, as usual, had to be heavily loaded. As this pier stood in the centre of the north channel, it was taken down to R.L. 2194·5. This level was safely reached on the night of 14th December, and the well was then filled in the same way as No. 6 (*Plate* VIII.). The arrangement of 3-inch pipes for draining the founds towards the pumps was, as before, found most satisfactory.

Erection of No. 3 Span.

In the meantime, work on No. 3 Span had been going on. The first thing to do was to make the piles; each pile consisted of two flat-footed 60-lb. rails, 21 feet long, riveted together, foot to foot; one end was sharpened like a chisel, and strengthened by a $\frac{1}{2}$-inch steel plate riveted on each side (*Fig.* 5, *Plate* X.); this nose was then hardened. The pile-driver, which was an old one lying at Chakdara, was 25 feet high, and its monkey weighed about $\frac{3}{4}$ ton; it was repaired and mounted on a raft formed of the two country boats; the monkey was worked by a crab. In all nine steel piles and three timber ones were driven; they were arranged in four parallel rows of three, the rows being $15\frac{1}{2}$ feet apart and the piles in each row $9\frac{1}{2}$ feet apart. Each row was braced diagonally with timber, and the different rows were connected by longitudinal distance pieces. The piles were driven into the river bed to a maximum depth of 11 feet, and it took about two days to drive in each steel pile; one was broken during this operation and had to be replaced. The first pile was driven on 7th November and the last on 3rd December. The heads of the steel piles were sheathed with wood bolted on.

On these piles three lines of steel joists were fitted. These joists were made up of 31-foot channels belonging to the roadway (the section is shown in *Fig.* 4, *Plate* X.); they carried the staging, and the span was then erected in the same way as before. *Fig.* 2, *Plate* XIV. and *Plate* XV. show this operation in progress.

The erection of the 3rd span commenced on the 12th December, and was completed with the riveting in eleven days.

Later on great difficulty was experienced in extracting most of the steel piles. Although 100-ton hydraulic jacks were used, it was found impracticable to draw some of them and they had to be cut.

Erection of No. 4 and No. 5 Spans.

The erection of the 4th span was delayed for a few days on account of the rapidity with which the work had gone on; as the contractor had not been able to supply stone for No. 5 Well sufficiently quick.

The erection of this span however commenced on 9th January, 1903, and was finished with the riveting on the 17th, eight days later; the staging was then transferred to the 5th and last span, the erection of which commenced on 27th January and was completed within some eight days.

For the 4th and 5th spans hoisting with the derrick was done by steam and not by hand ; an engine being geared to a 10-ton crab by a pinion and cog specially made for the purpose.

Permanent Training Works.

So far nothing has been said about the permanent training works, which were considered necessary to keep the river in the desired course.

On the north side the river runs almost touching the southern hornwork wall of Chakdara Fort, which is situated on a small detached hill, a prolongation of the hills which bound the valley on this side. It is therefore, owing to the general lie of the ground, impossible for the river to encroach on this bank; and all that was necessary was to protect the hornwork of the fort. For this purpose the bank of the river was trimmed at a slope of about $\frac{1}{3}$ during the cold season of 1901–02 when the river was first diverted ; and the whole length of the hornwork, from the north abutment upwards, was protected by heavy boulder pitching, with the stones carefully laid as headers and the toe carried well down below the bed of the river; up stream, above the fort, the pitching was curved round into the bank.

On the south bank several training works, which had been constructed for the protection of the old suspension bridge, still existed in a more or less damaged condition ; they were four in number. These bunds were re-aligned and constructed anew ; they were made of boulders, with the facing stones laid as headers ; the slope of the face was $\frac{1}{3}$, and that of the back $\frac{2}{3}$; width at top 5 to 6 feet (*Fig.* 6, *Plate* X.). The toe of the face was carried well down below the bed of the river, the up-stream ends were bent round into the bank and the down-stream noses were protected by wire sausages. A good deal of work was done on them during the spring of 1902, and they were extended and completed during the autumn when the river had been diverted to the north bank. The land between the bunds was thickly sown with tree seeds. *Plate* V. shows the position and lengths of these bunds.

Wing Walls.

The wing walls of the two abutments were entirely separate from the masonry of the abutments themselves. They were built in dry stone, like ordinary retaining walls, with their foundations carried well down behind the protective training works which enveloped the abutments on both banks.

Approach Roads.

The level of the tops of the piers was governed by the observed maximum heights of floods. Observations of course did not extend back beyond 1895 ; and the maximum recorded level was at R.L. 2243 in 1899. On account of the general level of the valley it is improbable that a much higher flood can be attained at any time, as any further flood would spread over the surrounding country. The level of the tops of the piers was fixed at R.L. 2248; and this gave a level of R.L. 2255 to the roadway. The approach road on the south bank rose at $\frac{1}{40}$ to this level, and that on the north bank fell at $\frac{1}{20}$; on account of the position and level of the hornwork of the Fort, and its entrances, it was not feasible to put in a gentler gradient on the latter side.

Chakdara was visited on January 15th, 1903, by T.R.H. the Duke and Duchess of Connaught, and in commemoration of their visit H.R.H. the Duchess gave permission for the bridge to be named after herself.

Completion of Work.

On March 4th the bridge was opened for public traffic by the Hon. Lieut.-Colonel H. A. Deane, C.S.I., Chief Commissioner and Agent to the Governor-General, North-West Frontier Province. *Plates* XVII. and XVIII. give general views of the bridge, taken on the opening day.

The old suspension bridge was then dismantled, and its piers cut down to ground level; the diversion works in the river bed were levelled, and the river once more allowed to resume its natural courses.

The total time taken in the construction of the bridge was almost exactly 18 months, from September, 1901, to March, 1903.

Details of Work.

A few details of the work, not included above, will now be given.

Masonry Piers.

These were built of coursed stone laid in P.C. throughout. The courses were 6 inches thick, and the proportion of P.C. to sand in the mortar varied from 1 to 1 to 1 to 5; *Plates* VI. to IX. give full details of the construction of the piers and the proportions of the mortar, concrete, etc. The stone used was a hard mountain limestone, quarried near Chakdara.

In Nos. 1, 2 and 3 Wells, for a height of some 25 feet from foundation level, Robinson's Portland cement was used; in all the remainder of the work nothing but Indian Portland cement (Arbuthnot's Yellow Brand); this latter was very satisfactory cement, and much cheaper than any English brand. A quick-setting cement (*e.g.*, Roman) would have been most useful in some of the foundation work, used in connection with the Portland cement, to protect the latter from damage by water.

Where pressure was put upon the masons to fill interstices carefully with spalls, 25 cubic feet of dry mortar per 100 cubic feet masonry was used; the barrel being taken at 5 cubic feet and measurements made loose. At other times 30 cubic feet per 100 cubic feet masonry was used. The greatest amount of masonry laid per mason per diem was 75 cubic feet in foundation work.

Below ground level, and at ground level, each pier was well protected from scour by rings of wire sausages, filled with river boulders. This was very desirable as the soil just round the piers was much loosened by excavation.

Pumping Details.

The total amount of fuel expended in pumping was 330 tons of coal and 400 tons of wood. The combined length of the shafts of the six wells was 200 feet. Of this amount of fuel Nos. 1, 2 and 3 Wells consumed 260 tons of coal and 160 tons of wood; but it must be remembered that No. 2 Well had to be sunk practically twice.

The maximum yield of water in Nos. 2 and 3 Wells was not less than 125,000 gallons per hour; whereas in the remainder it varied from 25,000 to 50,000 gallons per hour. During the sinking of the wells, fires were drawn and the boilers washed out once a week, *whenever practicable;* but this was not always possible, and in this sort of work the main consideration is to sink the wells as quickly as possible. Where the influx of water is very heavy, and almost up to the capacity of the pumps, it is most desirable to keep the water under at all costs.

Girders.

The girders (of the usual **N** type) were manufactured in Bombay by Messrs. Richardson & Cruddas from English steel. The weight of steel in each span was 100 tons. The maximum weight of any one piece was $2\frac{1}{4}$ tons, and the maximum length 33 feet 6 inches, these being the boom pieces. The number of joints in each upper boom was three, and in the lower boom four.

Riveting and Erection.

Seven to eight riveters' gangs were usually at work; the best gangs would each complete one main boom joint in the day, with only some 5 per cent. of rivets that would not pass the subsequent hammer test. As the work proceeded men were weeded out and replaced, until seven or eight very good gangs had been obtained.

Roadway.

The roadway consisted of arched steel plates, with longitudinal side channels, carried on heavy rolled steel cross girders with longitudinal rolled steel rail-bearers, 2 feet 6 inches apart (the gauge of the future railway).

The flooring plates were levelled up with asphalte, and a surface of $\frac{3}{4}$ inch stone ballast laid.

The usual expansion arrangements were provided for each span; the expansion flooring plate being protected from clogging by a loose hood of galvanized corrugated iron, bolted on to the floor plates on either side.

Bed Stones. The bed stones were finely chiselled, and set in cement; the upper surfaces were coated with a mixture of tar, kerosene, sand and lime, in order to ensure a perfect contact with the cast-iron bearings. Where necessary, thin lead sheeting was introduced between the end bearing-plate and the cast-iron saddle.

Holes for the Lewis bolts were drilled in the bed stones after erection and the bolts then leaded in.

After erection had commenced it was discovered that there was a constant difference in height between the fixed end and expansion bearings; this had to be taken out in the bed stones, after jacking up the span, and allowed for in the remaining spans.

Paint. All the girders were scaled by the application of caustic soda before being painted, as it was found that the coat of paint given in Bombay had covered many rusty patches. After being scaled the surface of the steel was well washed with soap and water; then a coat of raw linseed oil was applied; and, finally, two coats of paint. All joints before riveting were treated with raw linseed oil.

The paint, red metallic oxide, was of Indian make; it was purchased in dry powder, and ground in oil as required at Chakdara. The linseed oils used were mostly Indian; they were blended before use. The proportions used were 8 lbs. paint powder to 5 lbs. boiled linseed oil; the paint was twice ground, and $1\frac{1}{3}$ lb. turpentine finally added. In each span some 20,000 square feet of steel had to be painted, and 3,000 square feet tarred, making a total of 100,000 square feet to be painted in all. 3 lbs. of dry paint covered about 100 square feet (two coats).

Method of Work. The general principle of work was to carry out as much as possible by artisans and coolies receiving a daily or monthly rate of pay, and working directly under strict supervision; while only such work as involved coolie labour, or which required little supervision, was let out to contractors. Thus the construction of the diversion works, both bunds and tail-races, was carried out almost entirely by contract, the only agreement being the rate to be paid. Several contractors were employed, who worked more or less against each other in order to get further work.

The stone required for the piers was supplied by contract, the contractor delivering it at site, dressed and stacked in courses, ready for being passed before use. The bed stones, etc., were also quarried and supplied by a contractor.

The carriage of girders and stores from Dargai and Nowshera to Chakdara and the construction of the approach roads were also done by contract.

On the other hand all the well sinking, and everything connected with it, was done by departmental labour; as well as all girder-erection work, all work connected with the making and erecting of staging, etc., all pile-driving and riveting, and all carpenters', smiths', fitters' and masonry work; in fact everything requiring skill or supervision.

This method proved to be by far the most expeditious and economical manner of working.

In the girder-erection work a gang of Bombay khalassis were principally employed; and work on the staging was done by Punjabis. Occasionally these men were paid by piece-work, so much per ton; but a daily rate of pay was found to be best.

Cost of Erection.

The actual cost of erection worked out to about Rs. 34 per ton; this included man-handling and ferrying at site all girders and staging; laying and removing tram-lines; erecting and removing all staging for each span; erecting and riveting the girders, flooring, etc. The actual cost of erecting the girders themselves, apart from the staging and the riveting, was under Rs. 10 per ton. The carriage charges from Nowshera to Chakdara (57 miles by road) worked out to Rs. 21; and the cost of staging, gantry, tools and plant to Rs. 26 per ton; but only a part value of this plant was charged against the work.

NOTES CONCERNING PERSONNEL.

Hutting and Sanitary Arrangements, etc.

Accommodation had to be provided for the workmen as well as for the stores. A number of huts were built on the big island in the centre of the river; each hut being usually 100′ × 20′ (with partition walls), built of round stone laid in mud with a thatched roof.

For several months also all the men were fed through the agency of the Commissariat and Transport Department.

In the winter several hundred sheep-skin coats were purchased and issued to the men, chiefly to those working in the wells, as this involved working by night and usually in water.

Sanitary arrangements, on account of the proximity of the fast-flowing river, gave no trouble. Cast-iron latrine seats with mat screens were provided as necessary, and a small conservancy gang maintained.

The above applies only to men employed by Government; contractors had to make all their own arrangements to the satisfaction of the military authorities.

Medical Arrangements.

At Chakdara there is a small civil hospital under the charge of the local military doctor, in which all cases were treated. Extremely few cases of illness or accident occurred. The only deaths from accident were those of two men killed in No. 2 Well in January, 1902 (see above), and of a fireman who died from the effects of an accident in October of the same year. There were no deaths from disease, and no cases of serious illness. Only one serious non-fatal accident occurred, by which a carpenter lost his leg.

Subordinate Staff.

The subordinate supervising staff was composed entirely of natives of India, and no Europeans were employed. They consisted of :—

(*a*). A sub-engineer at Rs. 300 a month, who left after eight months work and was not replaced.

(*b*). A foreman of works, at Rs. 100 to Rs. 125, in general charge.

(*c*). A mistri at Rs. 65, employed chiefly on night work.

(*d*). A mistri at Rs. 50, to supervise the erection work.

(*e*). A mistri at Rs. 25, to supervise all masonry work and the construction of bunds.

Rates of Pay.

After the stoppage of the issue of rations, the value of which was Rs. 3 per mensem per head, the average daily rates of pay of some of the trades were as follows :—

Smiths	12 to 13 annas.*
Fitters	Re. 1.
Riveters	12 annas to Re. 1.
Hammer men	6 to 10 annas.
Bellows boys / Hearth men / Dolly men	5 ,, 8 ,,
Engine drivers	12 annas to Re. 1.4.
Firemen	7 annas.
Masons	12 annas to Re. 1.
Carpenters	7 to 14 annas.
Bombay khalassis	Re 1.
Punjabi do.	6 to 9 annas.
Boatmen	7 ,, 8 ,,
Chokidars	5 ,, 7 ,,
Bihistis	6 ,,
Mochi	8 ,,
Coolies	4 ,, 8 ,, (the higher rates being paid for well sinking).

* One Rupee = 16 Annas.

A few individuals, who were specially good at their trades, received an anna or two more than these rates.

The daily expenditure on workmen's wages ran up to Rs. 120 during the first cold weather and Rs. 170 during the second cold weather, when more operations were in progress. This was of course independent of contract work.

Plant, Machinery and Stores.

The following is a list of some of the principal plant and machinery employed :— Plant and Machinery.

Portable Steam Engines (Marshall & Sons).—Two double-cylinder 10 N.H.P.

Two double-cylinder 8 N.H.P., with reversing link motion gear.

(Spare wearing parts and tube tools were procured with the above).

Pumps.—One hand fire engine pump for washing out.

Two 6-inch centrifugal pumps (Gwynne).

One 6-inch do. (Cherry & Wade).

(This last pump was more efficient than the other type. Each pump was provided with a wrought-iron sliding suction pipe, and with flanged bends and suction and delivery piping in suitable lengths, all of wrought iron. No cast-iron piping was purchased, as though cheaper its great weight makes it cumbersome to use.

Oxidized cotton belting was found to be more efficient than leather belting, as well as being much cheaper. Cotton belting requires a special paste for dressing).

Two No. 8 pulsometer pumps, with flanged bends and suction and delivery piping in lengths, all of wrought iron.

(The ordinary flexible steam hose was not found very satisfactory; the flexible steel or copper steam piping is much better).

Jacks.—Two screw jacks, Haley's 6-ton.

Two lift and traverse jacks, 4 and 5-ton.

Two hydraulic jacks, 100-ton.

Blocks.—Six Weston's patent differential blocks, 2-ton and $1\frac{1}{2}$-ton; four of them being fitted with 120 feet chain each.

About three dozen pulley blocks—single, snatch, double and treble, for rope from $\frac{1}{2}$-inch diameter to 2-inch diameter; also three blocks for $\frac{1}{2}$-inch and $\frac{3}{8}$-inch chain.

Country Boats.—Two large, and one small.

Chain.—600 running feet of $\frac{1}{2}$-inch and $\frac{5}{8}$-inch short link crane chain.

Gyns.—Twelve, made from 2-inch, $2\frac{1}{2}$-inch and 3-inch galvanized wrought-iron piping (legs 15 and 30 feet long).

Plough Steel Cables.—Six, $\frac{1}{3}$-inch to $\frac{3}{4}$-inch diameter, in 500-foot lengths.

Crabs.—Two 1-ton.
One 5-ton (mounted on a travelling platform).
One 10-ton.

Pile-Driver.—One 25-foot, with $\frac{3}{4}$-ton monkey.

Taps and Dies.—Both gas and water threads from $\frac{1}{4}$-inch to 3-inch; also one screwing machine, $\frac{1}{4}$-inch to $1\frac{1}{2}$-inch, and screw plates.

Paint-Grinding Mill.—One.

Mathematical Instruments, for setting out the piers; two 5-inch theodolites, two levels, 100-foot and 50-foot steel tapes, and 12-inch machine-divided steel rule.

The Gantry for erection was made at site (see above), as were also the riveting tools and two material trollies.

Staging was purchased or made, sufficient for one span of length 150 feet, width 25 feet, height 20 feet.

Stores.

The principal stores included :—

1,000 running feet of 12″ × 12″ Oregon pitch pine, in 25-foot and 50-foot lengths.

4,000 running feet of old rails, 60-lb., 21-feet to 24-feet lengths.

About 1,000 Deodar scantlings, 6″ × 4″ × 15′, 8″ × 5″ × 20′, and 10″ × 5″ × 10′, purchased as required.

1,000 Chil planks, 2-inch thick, purchased as required.

1,000 Bullas, 6-inch diameter, purchased as required.

Manilla rope, $1\frac{1}{4}$-inch to 5-inch, and 4-inch coir rope were purchased as required; about 18 coils in all.

Estimates and Costs.

Estimates and Costs.

		Estimate.	Expenditure.
I.	Preliminary Expenses ...	6,511	6,029
II.	Pumping Machinery ...	16,978	13,166
III.	Diversion Works	49,616	61,873
IV.	Piers	1,41,421	1,41,279
V.	Purchase of Girders ...	1,56,250	1,57,187
VI.	Carriage and Erection of ditto	56,689	43,988
VII.	Approach Roads	4,220	7,437
VIII.	Training Works	17,000	13,200
		Rs. 4,48,685	Rs. 4,44,159

Sub-head I. included the cost of surveys, hutting workmen and coolies, etc., and the cost of a small experimental 5-feet diameter well sunk in 1899--1900.

Sub-head II. was the part value of the pumping machinery purchased. About Rs. 34,000 was expended; but only a portion of this sum was finally charged against the work, the remainder being written off, as the machinery became available for other works, at part value.

Sub-head III. The excess on this was due to the attempt to divert the river to the north bank in the spring of 1902; all the bunds then constructed were washed away.

Sub-head V. included delivery at Nowshera Railway Station; the cost of painting was also charged against this.

Sub-head VI. included carriage from Nowshera to site and all erection and riveting charges; also part value of all tools, plant and machinery purchased for erecting and riveting.

Sub-head VII. The excess was due to the rate for earthwork being unavoidably higher than that entered in the estimate. The road was also made wider and more work done than originally allowed for.

Sub-head VIII. Saving due to the rates paid being less than those entered in the estimate.

To the total given above about Rs. 1,000 should be added to cover a few final liabilities incurred but not paid for by 31st March, 1903.

Defence Works.

The defence works for the bridge formed a separate work and item in the Military Works Budget. They cost Rs. 15,000, and were completed in March, 1903. They consisted of :—

(*a*). A double two-storeyed blockhouse on the south bank.

(*b*). Alterations to, and enlargements of, the hornwork of Chakdara Fort on the north bank.

PAPER V.

THE LIGHT RAILWAY
DELHI CORONATION DURBAR, 1903.

BY

CAPT. H. A. L. HEPPER, R.E., AND LIEUT. C. L. MAGNIAC, R.E.

PAPER V.

THE LIGHT RAILWAY
DELHI CORONATION DURBAR, 1903.

BY CAPT. H. A. L. HEPPER, R.E., AND LIEUT. C. L. MAGNIAC, R.E.

PART I. CONSTRUCTION AND ROLLING STOCK.

By CAPTAIN H. A. L. HEPPER, R.E. (*Special Railway Officer*).

Gauge 2′ 6″.
Mileage :—

Main Line (Double)	4·00 Miles.
Amphitheatre Branch (Single)	1·78 ,,
Review Branch from junction with Amphitheatre Branch (Single)	1·45 ,,

or a total length of 11·23 miles of single track, in addition to which there was ½ mile of sidings at Kashmir Gate terminus.

INTRODUCTORY.

The Delhi Durbar Light Railway was constructed and worked, under the direction of officers of the Royal Engineers, with permanent way material and rolling stock specially designed for use on military railways. Sappers and Miners were employed on its construction; and the conditions, as regards the rapidity with which the work had to be completed, were similar to what would probably obtain in the case of a military railway constructed in average country. The following notes relative to the work will therefore, perhaps, be of interest.

The Railway was constructed mainly with the object of relieving the traffic on the roads leading from Delhi to the Durbar Camps. It was considered (and as events proved rightly so) that during the Durbar the vehicular traffic on these roads would be enormous, due not only to the rush of people from the City and from the Visitors' Camps and Hotels in its vicinity to the Central Camp, Polo Ground and Amphitheatre, but also to the numbers of visitors resident in the Central Camp who would require to use the roads to get to the Art Exhibition, the Fort and other places of interest in the city itself, whilst the concentration of crowds of people at the various functions, State and otherwise, might be expected to result in a state of congestion far in excess of that which any ordinary traffic would be likely to produce.

The area covered by the Durbar Camps was considerable. Some idea of its extent may be gathered from the following statement of distances from Kashmir Gate to places of interest:—Central Camp, 2½ miles; Polo Ground, 4 miles; Amphitheatre, 5 miles; Review Ground, 5½ miles. It was hardly to be expected that all those attending the Durbar would be able to bring their own conveyances with them; and some alternative means of locomotion was almost a necessity to enable people, unprovided for in this respect, to get from place to place at a reasonable cost and to render them independent of the hackney carriage, the charges for the use of which were sure to be extortionate.

It was originally suggested that a tramway laid along the side of the roads would meet the case, but this proposal was abandoned for various reasons in favour of a railway built on an independent alignment.

Apart from the fact that, except in a few places, the roads were not of sufficient width to allow of a tramway, worked by ordinary steam locomotives, being run on them during the Durbar with any degree of safety, the light loads and low speeds imperative under such circumstances would have combined to limit the carrying capacity of the line to such an extent as to render the whole project of doubtful value. It would, perhaps, have been feasible to run the line on the Alipur Road to the west of the ridge, but here the ground on either side of the road presented no greater difficulties to the laying of the rails than did the road itself.

Even given an alignment independent of the roads there still remained the possibility of working the line more or less as a tramway, that is to say without stations or regular stopping places and without an expensive traffic staff; the more so, as owing to the main line being practically a circular line, stations were not required for crossing trains. It was not thought possible, however, that under such a system of working the available stock (12 engines and 120 vehicles) could with safety be utilised to anything like the fullest capacity; whilst another serious objection presented itself in the question of the collection of fares. The General Service wagons could not readily have been adapted to give through communication; and, even had this been possible, it was doubted if the guard would be able to keep a proper check on passengers getting on to the train. The difficulties that would have been experienced in this connection can best be realised by those who saw the state of the traffic during the Durbar.

The considerations indicated above led to the adoption of an alignment independent of the roads. Stations, signals and telegraphic communication were provided; and the line was worked on the absolute block system in all respects as a railway. It was decided to utilise the permanent way material and rolling stock belonging to the Military Light Railway reserve, maintained by the Government of India for use in connection with military operations, and to construct and work the railway, by military labour as far as possible, under the direction of military engineers.

Since the line was intended for the use of the public it had to be constructed and worked under the provisions of the Indian Railways Act to a higher standard, as regards safety, than would be necessary in the case of a purely military railway, the working of which, moreover, would be much simplified by the absence of the somewhat complicated arrangements required for the collection of fares, prevention of fraud and disposal of cash.

Notwithstanding this the construction and working afforded some valuable experience from a military point of view, and provided an excellent opportunity of testing the capabilities of the military material and rolling stock under conditions which approximated sufficiently to those likely to be met with on service in India.

Alignment and Arrangement of Stations.

Index Plan (*Plate* I.) *and Section* (*Plate* II.).

The general scheme provided for a main line 4 miles long, from a point near the Kashmir Gate of the city through the Central Camp to the Polo Grounds, on which the bulk of the ordinary traffic was carried by means of a frequent service of trains run daily from about 8 a.m. till 10 p.m. In connection with this two branch lines were laid, for use on the occasion of special functions, to the Durbar Amphitheatre and Review Ground respectively. As a matter of fact however a daily service on the Amphitheatre Branch, worked by a shuttle train, was commenced some time before the Durbar, to suit the convenience of crowds of sightseers desirous of witnessing the rehearsals of the various functions or of seeing the Amphitheatre building itself.

The main line was laid as a double line, the two tracks at each of the termini being spread out and brought round to join one another in a single line loop. The Kashmir Gate terminal station was situated on the loop and there were six other stations on the double portion of the main line, which thus presented in effect a continuous single-line circular railway of 8 miles circumference, divided into thirteen sections, round which trains followed each other in rapid succession without the necessity of shunting. The branch lines were single lines in each case.

Some trouble was experienced in fixing the alignment of the main line so as to avoid encroachments on vested interests in the shape of camps already staked out and allotted to various departments, whilst it was important to keep the line on Government land in order to avoid claims for compensation.

The negotiation of the Ridge, so as to secure the best curves and grades with a minimum of work, was a matter of no little difficulty; and several trial lines had to be surveyed before a satisfactory alignment was obtained. Again the question of the limiting angle at which the track could safely be taken across the large number of camp and other roads, combined with the fact that the rail level was tied at these points, tended to make the selection of a suitable alignment for the main line a far more troublesome business than would be the case with a military railway. The location of the branch lines, however, was easy, the ground being for the most part level and open and free from camps or roads.

Plate VIII. shows the Mori Gate Station and the terminal arrangements at Kashmir Gate. The site of the terminus was fixed with special reference to the Art Exhibition (situated in the Kudsia Gardens) and to the suitability of the ground for the fan of sidings which connected with the loop in the trailing direction; whilst the proximity of Visitors' Camp No. 2 and the gate of the City rendered a station at Mori Gate a necessity.

The remaining stations are shown on the Index Plan. They were placed as conveniently as possible for the various camps they were intended to serve, having regard to the nature of the ground, gradients, etc.

In fixing the number of stations it was considered that, as the maximum number of trains likely to be run at one time was ten, a circular line with about thirteen sections would probably be the most suitable having regard to economy and convenience of working. The three spare sections provided against a general block. A greater number of stations would have made travelling between the termini very slow, not to speak of the cost of extra staff and of constructing and equipping the additional stations.

For block working purposes the stations were quite close enough, as trains could be run at 8 minutes' interval. Owing, however, to the congestion of road traffic produced at the many level-crossings, it was not found possible to run them as close as this during the Durbar.

Roughly speaking, after leaving Mori Gate the main line followed the toe of the eastern slope of the Ridge up to Flagstaff station; there it commenced to ascend, reaching the summit at chain 111·00. The descent on the western side was made with sharp reverse curves to avoid the Camp Telegraph Office, from which point the alignment followed the Alipur Road. Crossing the Najafgarh canal the line continued parallel to the Alipur Road until near its junction with the Durbar Road, when a turn to the south was made, parallel to the latter road but for a short distance only, the line again curving and following the Polo Ground Road up to the terminal loop situated at the back of the bandstand to the west of the Polo Grounds.

The junction of the branch with the main line was effected near the Durbar Road Station, the former crossing the Durbar and Alipur Roads and passing round the end of the East Indian Railway Central Camp Station. After running parallel with the East Indian Railway for a short distance the branch line turned northwards, skirting the Central Supply Depôt, and then bifurcated;

the Amphitheatre branch running almost due north across the plain to the Amphitheatre, the Review Ground branch following a westerly direction to the Review Ground. Loops were formed at the termini of both the branch lines and were made of sufficient length to hold twice the available rolling-stock, the terminal station in each case being situated about the centre of the loop.

Rolling Stock.

Locomotives. *Plate* III.

At the time the construction of the Light Railway was taken in hand the locomotives for the Military Light Railway reserve were under supply from England and it was hoped that they would arrive in India in time to be used at Delhi. This proved not to be the case and the contractors were only able to deliver three of them before the Durbar. Arrangements were therefore made to borrow nine engines from the Khushalgarh-Kohat-Thal Railway.*

Six of the latter were of one type,—*i.e.*, tank engines having four coupled wheels 2′ 3″ diameter, with a rigid wheel base of 4′ 0″, and a leading and trailing pair of wheels 1′ 7″ diameter with radial axle boxes, a hand-brake being fitted to the four coupled wheels. The weight in working order was 11·6 tons, with 6·5 tons on the coupled wheels.

These six engines had 8″ diameter cylinders with 12″ stroke, the valve gear being of the Joy type. The grate area amounted to 5·4 sq. ft.; the heating surface of firebox 25·98 sq. ft. and of tubes 196·85 sq. ft.; 386 gallons of water and 20 c.ft. of fuel were carried.

The three engines belonging to the Military Light Railway reserve were of similar design to the above except that the saddle tanks were prolonged to a level with the front of the smoke box and had a capacity of 400 gallons, the weights on the wheels being proportionately greater.

The remaining three engines, also borrowed from the Khushalgarh-Kohat-Thal Railway, were similar in all respects to the Military tank engines, but were provided with 4-wheeled tenders carrying another 400 gallons of water and additional fuel.

The Polo Ground terminal loop was originally laid to a radius of

* *The North-Western Railway is a State Railway on the standard gauge of* 5′ 6″.

The Khushalgarh-Kohat-Thal is a State Railway on the 2′ 6″ gauge and is worked by the North-Western Railway.

100 feet, but it was found that the six first-mentioned tank engines borrowed from the Khushalgarh-Kohat-Thal Railway could not always be depended upon to get round the curve without leaving the rails. The radius was, therefore, increased to 120 ft. after which there were no further derailments. The three Military tank engines, however, as well as the three tender engines borrowed from the Khushalgarh-Kohat-Thal Railway, had been fitted with radial axle boxes giving 6 inches greater play; and all took the 100 ft. curve easily.

The engines, which were designed to pull a load of 40 tons up 1 in 50, were called upon to perform their heaviest duty on the western approach to the ridge, from the Camp Telegraph Office to the summit. The grade here was 1 in 86, with two 150 ft. radius reverse curves of nearly 90° curvature each, separated by 50 ft. of straight. The engines took 15 fully loaded vehicles (30 tons gross, excluding weight of engine) on this part of the line with comparative ease.

From data obtained from the Khushalgarh-Kohat-Thal Railway the approximate consumption of coal and water of the engines, at 150-lb. pressure and normal load of 25 tons, was taken as under :—

Grade.	Coal, cwts.	Water, gallons.	
1 in 83	·33	35	Per mile.
1 in 100	·25	25	,,
Level	·10	10	,,
Stabled	·12	30	Per hour.

In making the complete circular trip of 8 miles on the main line, the actual consumption was found to be as under—

Coal... ... ... 1·125 cwts.,
Water ... ... 150 gallons,

in addition to which 1 cwt. of coal and 28 lbs. of wood were required for lighting up.

The fuel used was Bengal coal. Experiments with coke, with a view to reducing the amount of smoke, were not successful as the pressure could not be kept up, and moreover this fuel was found to be more liable to cause sparks. In view of the proximity to the line of tents and thatched buildings, all the engines were fitted with spark arresters, and there were no cases of fire caused by sparks from the engines.

Coaching Stock. *Plate* IV.

The Military General Service wagons, of which 120 were lent by the Military authorities for use as coaching vehicles, were built in Calcutta. They were small 4-wheeled open goods wagons, about 8′ 9″ × 5′ 6″ internal floor space and 4′ 0″ wheelbase, with ends 2′ 0″ and flap sides 1′ 6″ high above floor level, the latter being 1′ 9″ above rail level. The wagons were designed to carry 3 tons, the tare being 18 cwt.

Each wagon was supplied with a canvas awning, supported by a light wrought iron framing on four tubular wrought iron standards, and was provided with a hand-brake worked by a lever; whilst twelve of them, intended to be used as brake-vans, were fitted with a screw attachment for working the brake. This was found to be unnecessary as the hand-levers were sufficient for all ordinary purposes.

To adapt the stock to the special purposes of the Durbar passenger traffic, each wagon was provided with four light garden seats fixed transversely, the centre two being fixed back to back; the frames were of wrought iron, teak battens forming the seats and backs. Canvas curtains were also added at the ends of the wagons, laced to the awning, with the object of minimising the nuisance caused by smoke and dust.

The distance between tracks on the double line being 8′ 0″ only, screens of wire netting were fitted to the inner side of each wagon to prevent passengers putting their heads out. The railway, being practically a circular line, the inner side was always the same, and the possibility of accident to passengers when trains were passing each other was thus avoided. On the outer side of each wagon the hinged side was removed so as to allow of passengers getting in and out.

The central buffing and coupling arrangement proved efficient, but unfortunately did not correspond with that of any of the engines, rendering special links, etc., a necessity. Eye bolts fixed to the ends of the wagons for animal traction served for the attachment of light safety chains, provided specially in case of failure of the centre coupling. The treads of the wheels were unturned and rough, which caused a good deal of vibration but of course would in no way detract from the efficiency of the stock when applied to its legitimate use. Altogether the General Service wagons, as fitted up, formed very serviceable passenger vehicles and answered their purpose admirably. For running after dark each wagon was lighted by a hurricane lamp, hung from the framing of the awning.

Locomotive Staff.

The Locomotive Department was in charge of an experienced Foreman lent by the North-Western Railway. The staff employed under him, including the drivers, were all natives; and were borrowed from the North-Western and Khushalgarh-Kohat-Thal Railways. The work devolving on the Locomotive Department included the erection of all the wagons at Delhi and the fitting of them for passenger traffic with the seats, etc., specially obtained for the purpose; in addition to which the whole of the stock was repainted before being put into use.

The maximum staff employed during the Durbar was as follows:—

1 Locomotive Foreman, 1 Carriage Examiner, 12 Drivers, 12 Firemen, 5 Fitters, 1 Coppersmith, 1 Tinsmith, 1 Blacksmith, 1 Boilermaker, 1 Hammerman, 1 Shedman, 2 Carpenters, 9 Lifters, 1 Store Clerk, and 59 Cleaners, Pumpmen, Fuel Coolies, Fitters' Coolies, Chowkidars, Bhisties and Sweepers.*

The drivers were given no allowance for overtime, but were paid a consolidated rate with one day's extra pay for washing out.

CHARACTER OF ROAD AND ITS CONSTRUCTION.

Index Section Plate II.

The greater part of the railway was practically a surface line; and its construction, begun on the 1st of August 1902, presented no great difficulty from an engineering point of view, other than the fact that the time available for its execution was very short.

On the ridge section, however, *viz.* from chain 60·00 to chain 120·00, the conditions were less favourable, the ground being broken and rocky, whilst the ridge itself (chain 98·00 to 114·00), over which the line had to be taken, presented an irregular mass of practically bare rock, rising abruptly from 40 feet to 21 feet (at the lowest point) above the normal ground level. The difficulty of getting earth for the embankment, and the considerable amount of blasting to be done, were serious obstacles to the rapid completion of this part of the work.

To economise material the tracks of the double line were spaced throughout at 8 ft. centres only, and 5 ft. was fixed as the minimum

* *Cooly = labourer, chowkidar = watchman, bhistie = water carrier, sweeper = sanitary conservancy man, peon = messenger.*

distance of the nearest fixed structure. This infringed the Government of India Provisional Standard Dimensions for 2′ 6″ gauge; but, considering the nature of the rolling stock to be employed and the special circumstances of the Durbar Light Railway, the dimensions adopted were sufficient. For two tracks the width of formation was 16 ft. in bank and 20 ft. in cutting, allowing for 2′ 0″ side drains. On the single line 8 feet and 12 feet respectively were the measurements adopted.

The maximum gradient was 1 in 80. The sharpest curve was 120 ft. radius, at the Polo Ground terminal loop, where the space available did not allow of a curve of larger radius being adopted; no other curves were of less than 150 ft. radius; the radius of the terminal loops at Kashmir Gate, Amphitheatre and Review Ground was 200 ft. in each case.

Two companies of Sappers and Miners were detailed by the Military authorities for work on the construction of the railway; but owing to the unhealthiness of Delhi during the latter part of the rains their arrival was delayed until the middle of September, and most of the earthwork on the easier portion of the main line was completed by civil labour before that date. A good deal of the permanent way material was also carted and spread by contract, in order that there might be no delay in starting the plate-laying as soon as the Sappers and Miners appeared on the scene.

Lieut. M. R. Elles, R.E. (commanding No. 4 Company, Bengal Sappers and Miners) took over the construction of the main line from the Kashmir Gate terminus to the summit of the Ridge, whilst Lieut. F. S. Garwood, R.E. (commanding No. 4 Company, Bombay Sappers and Miners) with Lieut. J. B. Corry, D.S.O., R.E., undertook the remainder. The Officer in charge of each section was given a free hand to supplement his Company to any reasonable extent by civil labour and to purchase locally all construction stores other than those obtained on loan from the neighbouring State railways.

Under this arrangement each Commanding Officer, by using his Company as the nucleus of a comparatively large force of civil labour, was able to secure the best results in the direction of the thorough supervision of the latter; indeed the excellent organisation of the civil labour effected in this manner was a factor which contributed in no small degree to the completion of the work in a remarkably short time.

The coolies were paid and medically attended through the agency of the Companies. They were moreover housed in camps close to the camps of the Companies to which they were attached, and it was thus possible to exercise a control over them which proved of the greatest value at a time when, owing to the competition to obtain labour in Delhi, it was most difficult to obtain coolies or to keep those already on the work.

The task allotted to the Bengal Company comprised the worst mile of formation, approaching the Ridge summit from the eastern side, together with the sidings, watering arrangements and ashpits at the Kashmir Gate terminus. On the whole of this section the work in the formation was above the average of the rest of the line, and level crossings and culverts were numerous.

To the Bombay Company fell the rock cutting through the crest of the Ridge, the bridge over the Najafgarh Canal and, ultimately, the construction of the two Branch lines. Incidentally also the Bombay Sappers had to unload the whole of the engines, wagons and stores, for which purpose temporary sidings and transhipping platforms were constructed in connection with the Central Camp Station of the East Indian Railway.

As soon as the rails on the main line had been laid throughout, the Bengal Company's section was extended up to the Najafgarh Canal Bridge, and the construction of the Branch lines was taken in hand by the Bombay Company.

For purposes of maintenance, after the line was opened for traffic, the canal bridge remained the dividing point between the sections of the two Companies.

Immediately the Sappers and Miners reached Delhi the work was hurried forward with all possible despatch. A single line was run up to the top of the Ridge from the eastern side, and the completion of the earthwork on this difficult section was taken in hand by means of material trollies and wagons, which had to be worked by hand pending the completion of the bridge over the Najafgarh Canal and of the rock cutting at the summit of the ridge. At the same time the laying of the line from the East Indian Railway Central Camp Station to the ridge summit was pushed on as rapidly as possible, in order that, as soon as the Canal Bridge and Ridge-cutting were ready, the engines and rolling-stock (which began to arrive about the end of September at the Central Camp Station) might be utilised for the completion of the earthwork on the ridge section. The connection was completed by the 20th of October, from which time onward the work progressed rapidly.

As the track was laid, and as soon as the engines and wagons were available, ballast trains were run freely on all parts of the line, both for the distribution of stores and material and to consolidate the formation as much as possible before the opening of the line for traffic.

Dry stone retaining walls were freely used on the Ridge to reduce the quantity of material required for the embankment, a plentiful supply of stone being available from the main cutting at the Ridge summit.

This cutting, comprising about 16,000 c. ft. of rock, some of which was very hard, was taken out by a party of the Bombay Sappers in 24 days, dynamite being the explosive used. In addition to this a good deal of blasting had to be done to remove projecting masses of rock in the sidelong ground to the east of the Ridge near its summit.

Najafgarh Canal Bridge. *Plate* V.

The bridge over the Najafgarh Canal was built on timber piles driven into the bed of the canal, and consisted of 3 spans of 10 ft. centre to centre of piers. The girders, which were continuous over the three spans, were 12″ × 12″ fir baulks, and the rails were laid directly on them. Each pier carrying the double track consisted of two piles, one under each track, spaced 8′ 6″ centre to centre transversely, with a 12″ × 12″ fir transom securely strapped down to the pile heads with $2\frac{1}{2} \times \frac{1}{2}$″ wrought iron straps and 1-inch bolts. The effect of spacing the piles at 8′ 6″ whilst the tracks were spaced at 8′ was to throw the centre line of the track inside the centre of the supporting pile in each case and thus secure a condition of stable equilibrium. Each pier was firmly braced transversely by 9″ × 4″ sal planks, bolted to the piles and to the ends of the transom by 1-inch bolts; and the two centre piers were also braced together longitudinally to check vibration. Stone-in-mud retaining walls, pointed with lime mortar, were built round the abutment piers to support the earthwork in the approaches.

Circular piles of 10″ diameter were used, being lent, together with the rest of the timber and the pile driver, by the North-Western Railway. The piles were driven with a one-ton monkey to a depth of 12 to 15 feet into the bed of the canal, the driving being continued in each case until the last six blows at 6′ drop sent the pile down less than 3″. On an average one day was required to set and drive one pile. After driving, slight errors in the positions of the piles were corrected by springing them with a railway coupling screw during the completion of the bracing and superstructure. The bridge was completed by the Bombay Company in 18 working days; but constant stoppages of the work, caused by the breaking down of the pile driver which was a very old one, delayed its completion considerably.

Before the line was opened for passenger traffic light tie-bars were fitted to keep the correct gauge on the bridge, and angle iron guard rails were provided to prevent a wagon leaving the bridge in the event of a derailment in its vicinity.

There were no other bridges of any importance. With the exception of a 6 ft. arched culvert on the Ridge section at chain 68·50 and a 3 ft. arch near Mori Gate station, the remaining openings were all 1′ 6″ or 2′ 0″ flat topped culverts, unserviceable sleepers being used for covering them on account of the difficulty of procuring the local stone in sufficiently large slabs.

In the case of two irrigation channels, which crossed the main line near Mori Gate and Alipur Road stations respectively, the water level in the channels was higher than the rail level which was tied down by the close proximity of a level crossing in each case. This necessitated the construction of masonry syphons to pass the water under the line.

Two large cast iron pipes had also to be crossed, *viz.*, the rising main from the Municipal pumping works on the bank of the Jumna to the reservoir on the Ridge and the falling main from the reservoir to the City. Both these pipes were about 1′ 6″ diameter and laid close to the surface of the ground. It was considered advisable to build masonry walls on either side of the pipe, in each case, and to cover with unserviceable sleepers clear of the pipe, so as to avoid the risk of damage during the passage of trains.

It was necessary to allow a good deal of waterway on the Ridge section as the drainage off the rock was considerable. A regular system of catch-water drains was made on the Ridge above the line in connection with the culverts, the arrangement of the rock strata, which dipped at an angle of about 60°, fortunately rendering this fairly easy.

The main line was fenced practically throughout with material borrowed from the North-Western Railway.

It may not be out of place, at this point, to draw attention to the great extent to which the Durbar Light Railway was indebted to the adjacent Government line, which helped loyally with staff, stores, labour and materials; and in recording the history of the former the assistance rendered by the Management of the North-Western Railway must not remain unacknowledged.

As mentioned above the work was commenced on the 1st of August 1902. The main line was inspected and passed for 12 miles an hour by the Senior Government Inspector, Lucknow, on the 29th November, and was opened for public traffic on the 1st of December.

Permanent Way, Stations, Etc.

Permanent Way. *Plate* VI.

The permanent way formed part of the Military Light Railway Reserve, and was lent by the Military authorities. It consisted of 21 lb. flat-footed rails, with stamped steel sleepers weighing 28 lbs. each and provided with reinforced lugs, a steel key driven outside the rail constituting the fastening. The fish-plates, weighing 4·9 lbs. per pair, were secured by four ½″ fishbolts with cup-shaped heads and square necks, the nuts being ⅞″ square and ½″ deep.

The rails were mostly in 12-foot lengths, but a proportion of 24-foot rails was also supplied. For the purpose of keeping the joints square on curves a small percentage of rails was provided 12′ 3″ in length; these were distinguishable from the 12-foot rails by having three holes at each end.

Some difficulty was experienced at first as the foot of the rail could not be got between the lugs of the sleeper even by canting the rail on one side; and, when the platelaying was commenced, the practice was to thread the sleepers on from the end of the rail and thus make up complete rail lengths which were easily placed in position. Later on a plan was adopted which proved to be far more expeditious than the above method. The rails were placed in position and several lengths fished together, the sleepers were then held up against the rail by a man stationed at the end of each, when one blow with a hammer on the rail caused the bottom flange to drop between the lugs of all the sleepers, the same proceedure being followed to get the other rail in. This process, though it sounds awkward, was in practice very rapid when the men became properly drilled, and was particularly useful in laying with the joints staggered.

The sleepers were laid 7 to the 12-foot rail or 14 to the 24-foot rail, the joint sleepers being spaced 1′ 4″ centre to centre in each case.

In laying the main line care was taken to keep the joints square in the usual way, the 12′ 3″ rails being used for the purpose on curves. So much time, however, was taken up in this way that it was decided to lay the branch lines with the joints anyhow; this was done and the progress was found to be much more rapid, whilst the laying of the 200 ft. loops at the Amphitheatre and Review Ground was accomplished without bending the rails; the line was easily slewed before keying up, and the staggered joints prevented the polygonal appearance which it was found almost impossible to avoid on sharp curves laid in the ordinary way even when the rails were bent.

On the main line, on curves of 150 ft. radius and less, the rails were bent with 3-roll rail benders, two of which, suitable to the section of rail, were obtained from the Military Reserve stock. Curves of 150 ft. radius were numerous; the superelevation given was $1\frac{1}{2}$ inches, the gauge being slackened $\frac{3}{8}$ of an inch by driving one of the keys inside.

No allowance for expansion was made in platelaying as the line was laid in September, when it was still hot, and was intended for use in the cold weather only.

The points and crossings were of the ordinary State Railway type for flat-footed rails, with flat-footed stock rail and built-up crossings on steel chairs.

For use with wooden sleepers dog spikes of the ordinary pattern, $\frac{3}{8}'' \times 3''$, were provided.

No ballast was used, the line being earth packed throughout; and the road stood well under a heavy traffic, except near Alipur Road Station where the soil was of a very light nature and rapidly turned into dust under the vibration.

The fastening of the rail to the sleeper proved most effective; no signs of creep were noticed anywhere; and, owing to the fact that the keys and fishplates did not foul each other, the sleepers could be placed under the joint if desired. With joints staggered and rails jointed on a sleeper in this way it was found that a road could be made good enough for low speed without any fishplates at all.

The platelaying did not afford much reliable data regarding the speed with which a military line could be laid with this material under service conditions. Most of the work had to be done before any rolling-stock was available, and to save time the rails and sleepers were carted and spread by contract before the platelaying proper was commenced. The rate of progress under such conditions was naturally greater than would be possible if all the material had to be worked up by train as the line advanced. On the other hand, the large number of level-crossings on the main line tended to check the linking up considerably in places, and far more labour was subsequently expended on getting a good surface on the road than would be at all necessary for military purposes.

Level Crossings.

A feature of the railway was the large number of level crossings both over public and camp roads. On the main line there were 24 double-line crossings, with two single-line crossings on the Kashmir Gate loop.

The standard opening allowed was 18 feet in the clear; but four of the main line crossings were twice this width, with double gates closing across the line. The branch line crossings of the Durbar and Alipur Roads were also provided with double 18 ft. gates, the latter having islands in the centre to facilitate the control of the road traffic.

The rails at level crossings were laid on wooden sleepers and the guard rails were secured by cast iron distance blocks and $\frac{1}{2}''$ bolts.

The type of gate adopted was perhaps somewhat heavy for a temporary line, but it was expected that they would have to withstand considerable rough usage. Lamps of ordinary North Western Railway pattern, showing red and green lights, were provided, fixed to the gate headstocks; and the Rajpur Road level-crossing was in addition protected by dwarf signals placed 300 feet on each side of the gate and worked from it.

The gatemen employed were native pensioners and reservists obtained through the Recruiting Staff Officer at Delhi, and trained by, and under the orders of, the O.C. Sappers in each section; and each of the more important gates was in charge of a British soldier. Small grass huts were provided for the gatemen to live in.

The numerous level-crossings added considerably to the difficulties of working the line; but the gatemen were well trained in their duties, before the rush of traffic commenced, by the officers of the Sappers and Miners, and no mishaps occurred. The two level crossings near the Polo Ground loop were a source of some anxiety at one time, as the block of vehicles on the roads during the polo matches was very great; however a couple of mounted military police, subsequently obtained for each of these gates from the 4th Dragoon Guards and Royal Horse Artillery respectively, saved the situation.

The total number of level-crossings on main line and branches amounted to 32, of which 6 were double and 19 single gates, the remaining 7 being fitted with chains only.

Watering Arrangements and Ashpits.

The main line was crossed at three places by irrigation channels, *viz.* near Mori Gate, Alipur Road and Polo Ground stations.

During construction all these were used for watering engines by means of buckets or pumps; but for actual working after the line was opened the only supply for the main line was at the Kashmir Gate terminus (*Plate* VIII.).

The water was taken from the irrigation channel near Mori Gate; and, as the supply was intermittent, a large reservoir capable of holding over 200,000 gallons was excavated near Mori Gate station, the spoil being utilised for making up the formation at a large nullah between the Police lines and Mori Gate station. Water from the irrigation channel kept this reservoir full by gravitation.

A circular 5,000 gallons tank, borrowed from the Oudh and Rohilkhand Railway, was erected on a polygonal sleeper stack close by, the top of the tank being 20 ft. above the water level in the reservoir. The water was raised into this high service tank by two hand lift-pumps on an independent sleeper stack.

The pumps were of the "New Deluge" bilge-pump type, made by Messrs. Jessop & Co., Calcutta, cylinder 8½″ diameter, stroke 6″, with a capacity of 60 gallons per minute (3,600 gallons per hour) at 50 strokes per minute. They were fitted with 3″ India rubber suction hose and proved most efficient. Only one was used at a time, the second being provided in case of break down. To work one pump continuously 12 men were required, in three reliefs of four men each.

From the high service tank the water was taken by a 6″ main, fitted with the necessary valves, to a 6″ water column at Kashmi Gate station, the rail level at the latter being 10 ft. below the ground level at the high service tank. A 4″ main from the water column supplied a washing out hydrant near the ashpits.

There were two ashpits, each 8′ wide, 60′ long and 2′ 6″ deep increasing to 3′ in the centre. The running rails were 75 lbs. flat-footed rails laid directly on double rail girders, which were made of two similar rails inverted, placed transversely across the pit at 6 ft. intervals. The walls of the pits were built in rough masonry on 6″ concrete founds, and dry rubble stone floors were provided.

A small stream of waste irrigation water crossed each of the branch lines near the commencement of their respective loops, and was used for watering the engines on the days of the Proclamation Ceremony and Review.

For the use of the Amphitheatre branch line daily train a 400-gallon tank, erected on a sleeper stack with a pump similar to those at Mori Gate, was provided. On the Review Ground branch buckets were used for filling the tanks, as the line was only used on the day of the Review.

Stations. *Plate* VII.

The station buildings were temporary thatched structures, comprising, under the same roof, a small office with window for the issue of tickets and an open passenger waiting shed.

The platforms, 150′ long, 20′ wide and 12″ above rail level, were enclosed by fencing made of bamboo trelliswork 4′ high, fixed to stout uprights with a horizontal timber rail 12″ from the top. A turnstile was provided near the centre for passengers entering the platforms, the exit gates being at the ends.

The front edge of the platform, which was 3′ 6″ from the centre of the nearest track, consisted of broad gauge deodar sleepers borrowed from the North-Western Railway and fixed on edge. These were slightly bevelled at the ends to allow of a triangular hard wood stake being driven into the ground between each two consecutive sleepers, the stakes when driven being flush with the front of the platform. Each sleeper rested on the heads of two wooden pegs driven into the ground to support it at the correct level of 12″ above rail level. Except where the line happened to be in cutting, the platforms were sloped back from the front edge to economise material.

Signals and Interlocking.

All signal and interlocking material was lent by the North-Western Railway, and was consequently of North-Western Railway standard type.

Each station was provided with a starting and home signal for each direction. The starting signal, fixed a short distance in advance of the platform, controlled the entrance of trains into the block section beyond; it was worked by hand and was provided with a lock of the Annet type, the key of which was kept in the personal custody of the Station Master.

The home signals were fixed 800 ft. in rear of their respective starting signals, and were worked by wire from the platforms. All signals had square ended arms and were absolute stop signals. There were no distant signals.

The Durbar Road Junction (*Plate* IX.) was fully interlocked, and fitted with main and branch home and starting signals on bracket posts. The points and the signals were worked from a 10-lever frame near the points, and the home signals were slotted from the platforms of the Durbar Road station. The starting signals were slotted also, the control in this case being worked by hand levers on the post, fitted with locks as in the case of the other starting signals.

The points at the junction of the Amphitheatre and Review Ground branches were fitted with locks of the Annet type to lock in either position, and the connection with the sidings at Kashmir Gate was also keylocked.

The temporary points on the branch line near the Central Camp station, for the engine loading siding and Supply Camp siding, were removed when the branch was opened for traffic.

MAINTENANCE.

The line was maintained throughout by the Sapper and Miner Companies, being divided up into gang lengths in the ordinary way. The Bengal Company had charge of No. 1 Section, from Kashmir Gate (including the sidings) to the Najafgarh Canal; the Bombay Company of No. 2 Section, from (and including) the Canal Bridge to the Polo Ground, with the two branch lines.

An Engineering Manual (Appendix D), based on the Rules for Indian Railways, was issued for the guidance of all concerned; in addition to which printed rules for each level-crossing gate were provided, more for the information of the public than for the guidance of the gatemen who of course were unable to read them.

The Engineering Manual has been included in this paper with the view of giving some idea of the duties and responsibilities devolving on the officers and men of the Sappers and Miners during the time that the Light Railway was open to Public Traffic. The officers had to train their men, and also the native gate-keepers, in the strict observance of a number of rules, the value of many of which, it may be imagined, the men were unable to appreciate, at any rate to start with.

The difficulties of working the line were enhanced by the large number of level crossings and by the considerable amount of trespassing which it was almost impossible to prevent. Between 5 p.m. and 7 p.m. the traffic on the roads and Railway was at its height by reason of the crowds returning to their quarters after the Polo matches, etc. At this time special vigilance was required on the part of all concerned, owing to the presence of the fog peculiar to cold weather evenings in the plains of Northern India combined with the thick dust which was one of the features of the Durbar gathering.

A good road was maintained throughout by the Sappers and Miners in spite of the heavy traffic and the absence of ballast.

Having regard to the fact that practically 120,000 persons were carried on the railway, with a total train mileage of 8,567 train miles, under conditions which were certainly unfavourable to safe working, it speaks well for the maintenance and running staffs that there was not a single accident.

To prevent dust the experiment was tried of sprinkling the line with crude petroleum. A 400-gallon tank was mounted on a truck and provided with a perforated pipe for sprinkling the oil, the holes in the pipe being $\frac{1}{32}''$ diameter at $\frac{1}{2}''$ pitch.

Unfortunately the oil did not arrive until late in December, when trains were running at 15 minutes' interval, and the experiment had to be made at night; 400 gallons of oil were sprinkled on the up line from Kashmir Gate to Durbar Road (about $3\frac{1}{4}$ miles), and proved effective in laying the dust; but the first train the next morning lost so much time owing to the greasing of the rails that the process could not be repeated.

Arrangements for Dismantling.

The Durbar Light Railway was closed for traffic on January 18th 1903, and the dismantling was commenced at once.

All rolling-stock, permanent way and stores borrowed from Railways were taken up to the Central Camp station, and loaded into broad gauge wagons for return to the Railways concerned.

The portion of the branch line which ran parallel to the East Indian Railway passenger sidings was at a level of 3′ 6″ above them, and a temporary platform which had been made to facilitate the unloading of material when it arrived served for its despatch.

The engines were loaded, as they had been unloaded, by means of a temporary dock into which broad gauge wagons were run, a 2′ 6″ gauge siding being laid in continuation of the broad gauge dock line but 3′ 6″ above it, connecting with the branch line. The engines were run direct on to the broad gauge trucks without difficulty and were wedged up on timber rails. The General Service trucks were loaded by hand into the wagons, the weight being 18 cwt. only.

All locally purchased material, recovered from station buildings, etc., was collected at Kashmir Gate before the permanent way was taken up, and sold by auction.

As soon as all stores and material had been collected, either at Kashmir Gate or Central Camp station, the dismantling of the permanent way was commenced; and the line was finally "rolled up" on the Central Camp station.

The dismantling of the whole line, including the despatch of material, rolling-stock and stores, was completed by February 9th, having occupied 22 days. In one instance the Bengal Company, under Capt. H. R. Stockley, R.E. (who had returned from furlough and taken over command during the Durbar), dismantled and loaded up 2,000 yards of double track in 6 hours.

COST.

An abstract of the total cost of constructing and working the Light Railway is given in Appendix B. The figures as regards value of stores and material to be recovered are approximate only, but they are probably fairly accurate. The total expenditure is given at Rs. 1,25,856, whilst the earnings (Appendix C) were Rs. 68,222.

The net cost of the railway thus amounted to Rs. 57,634; but of this amount nearly Rs. 30,000 represents the carriage of engines, rolling-stock, stores and material to and from Delhi (paid to the North-Western State Railway and hence a credit to the Government of India); so the actual ultimate cost to Government may be taken at under Rs. 30,000.

CONCLUDING REMARKS.

In closing these notes it may not be out of place to consider briefly the lessons learnt at Delhi in their application to the question of the construction of Military Light Railways.

To begin with, the rapid completion of such lines being the principal object in view, it is of the first importance that the alignment should be carefully surveyed before the construction is commenced. At Delhi, owing to the short time available, work on the formation had to be started before the survey had been completed throughout; an arrangement the drawbacks of which can only be fully realised by those who have tried it.

It may not, in all cases, be possible to foresee in what directions military railways will be required; but, on the other hand, likely routes *may* suggest themselves; and in any case the greatest rapidity and economy of construction will not be secured unless the alignment has been carefully selected under conditions favourable to the preparation of a careful and detailed survey.

The preparation of the formation is principally a question of the organisation of labour and supply of tools and material. A military railway generally presupposes military labour; but it is hardly possible that this will ever be available in sufficient quantity to do the work unaided, and civil labour will have to be largely employed. In the case of India, where the Government have, in the North-Western Railway, a large State Railway organisation in extension of which any Military Railway would probably be built, there appear to be some arguments in favour of adopting a civil organisation under R.E. officers for the construction of Military Light Railways, to be drawn when required from the Government line. It is not necessary, however, for the purposes of this paper to discuss this aspect of the case; and whether the organisation be a purely civil one under R.E. officers on the lines of the Government of India Survey Department,—or one largely civil as regards untrained labour, but with a trained and disciplined military nucleus, as was the case at Delhi—the main point, which it is desired to put forward, is that some sort of organisation is desirable in peace time, which can be applied at once to the proper regulation, supervision, payment and possibly housing and feeding of the very large amount of civil labour which it will be necessary to employ immediately the construction of a Military Railway has been decided upon.

Similarly, in order to secure the best results in the direction of rapid construction, the reserve of railway material held in stock should include, in addition to the permanent way and rolling stock, a supply of suitable tools of all sorts, bridging material, watering appliances and material and spare parts for rolling stock.

As regards the platelaying, it would appear that far too much stress has, as a rule, been laid on the importance of being able to lay the track with extreme rapidity. Much of the literature appertaining to Military Railways has been devoted to the description of very light forms of permanent way and to the organisation of labour necessary at rail head to ensure the maximum speed of linking in. In some cases rails as light as 10 lbs. per yard, made up into complete sections of track (as in the Decauville system) have been proposed; and various forms of joint have been suggested to obviate the delay caused by the use of the ordinary fishplates and bolts.

The experience of the Durbar Light Railway, however, goes to prove that it is the preparation of the formation and the supply of material at rail head which really govern the rate of progress; and that, even in a comparatively easy country, the platelaying is a matter of secondary importance. The idea, sometimes advanced, that a little shovelling in places is all that is necessary to get a formation good enough for a Military railway is misleading. The line *must* be made with such grades and curves as will give a carrying capacity sufficient to justify its construction; and this, even in ordinary country, will preclude all possibility of the formation being prepared, except perhaps for short distances, at anything like the rate at which it would be possible to lay the rails.

There is no object therefore in risking the ultimate efficiency of the line by using very light rails; whilst the practice of using ready made up sections of track greatly complicates the question of loading and transport. The latter system was given a trial at Delhi, but was abandoned in favour of the ordinary method, and the best results were obtained by allowing the joints to run anyhow.

The Military Reserve material proved most satisfactory in practice, and could hardly be improved upon as a type. The adoption of a 30 or 35-lb. rail, however, would enable more powerful engines to be used; and would not, it is believed, affect in the smallest degree the question of the date of completion in the case of a railway constructed in ordinary country.

PART II. TRAFFIC WORKING.

By LIEUTENANT C. L. MAGNIAC, R.E. (*Traffic Officer*).

COMPOSITION AND NUMBER OF TRAINS.

From the 1st to the 22nd of December 1902 the trains were made up into sets of twelve vehicles, consisting of four first class, seven second class and one brake-van. The total accommodation per train was 48 first, and 112 second, class passengers.

From 23rd December 1902 to 17th January 1903 the number of carriages forming each train was increased to five first, nine second class and one brake-van, and the brake-van was also fitted up with four garden seats. The total accommodation per train was then 60 first, and 159 second, class passengers.

The main double line to the Polo Ground was opened on the 1st December 1902 with three trains each way. The number of trains each way was increased to 9 on 12th December, to 21 on 18th December, and to a train every 15 minutes between 8 a.m. and 10 p.m. from 26th December to 10th January; after the latter date trains were run at intervals of 30 minutes up to 15th January and at intervals of 1 hour from 15th January to 17th January, when the line was finally closed to passenger traffic. During the Durbar period six trains, of 15 vehicles each, were run at intervals of about 15 minutes on the double line.

The Amphitheatre branch was opened for the carriage of passengers on the 12th December 1902 and closed on the 12th January 1903. The branch line train was run every morning from Kashmir Gate to Durbar Road, made a succession of trips between Durbar Road and Amphitheatre stations, varying from four at the commencement to fourteen on the occasion of the Assault-at-Arms, and returned to Kashmir Gate at the end of the day.

The maximum number of trains run on the main line in one day was 46 in each direction; and on the same date the Amphitheatre branch train ran through from Kashmir Gate to the Amphitheatre and back, and made an additional eight trips between the Amphitheatre and Durbar Road Junction. The maximum number of train miles run in one day was thus—$8 \times 46 + 2 \times 5 + 16 \times 1\frac{3}{4} = 406$ train miles. The total number of train miles run was 8,567 (Appendix C.)

Special Trains to the Amphitheatre and Review Ground.

On the occasions of the Proclamation Ceremony and Review the whole of the available stock was run direct to the Amphitheatre and Review Ground respectively, the trains being started from Durbar Road at 10 minutes' interval.

Nine trains were run to the Amphitheatre for the Proclamation Ceremony, the total available accommodation being 1,410; first class passengers only were carried. The number of tickets issued for the Proclamation Ceremony was 952; and in addition to this 150 mutiny veterans and 50 officials were carried by train, a total of 1,152 passengers.

Speed.

The line was passed by the Senior Government Inspector, Lucknow, who allowed a maximum speed of 12 miles an hour on the main and 10 miles an hour on the branch lines.

The stoppage at each station was two minutes; and it was found that a train could complete the circle of the double line, and also coal and water, in 90 minutes.

Stations.

Each station was provided with a combined booking, telegraph and Station Master's office $14' \times 14'$, and a passenger waiting hall $14' \times 14'$.

Staff quarters for the superior and menial traffic staff and for the police were erected in the vicinity of the station, and the necessary latrine arrangements for the staff were also provided. No shunting was performed at any station except at Kashmir Gate and Durbar Road Junction stations, a description of which is given below.

Watering arrangements were provided at Kashmir Gate station and at the Review and Amphitheatre terminals.

Kashmir Gate. *Plate* VII.

At the main terminal station at Kashmir Gate six sidings terminating in dead ends were provided, each capable of accommodating two trains of 12 trucks; and these sidings were connected by a gathering line to a main siding taking directly off the terminal loop.

The Locomotive yard consisted of one long siding terminating in a dead end (a continuation of the main siding) and a short branch siding, each siding being provided with an ashpit.

A stop signal was erected between the Traffic and Locomotive yards entrance points, and all engines were piloted out of the Locomotive yard by the Points Jemadar. Before admitting a train from the station yard on to the main line, "line clear" was first obtained from the station next in advance, and "line clear" was also similarly obtained before returning a train from the main line into the sidings.

Durbar Road. *Plate* VIII. The cross-overs at Durbar Road Junction from the up and down lines into the branch line were interlocked; and special rules were framed for working through trains to the branch lines when main line trains were running.

System of Train Working.

The system of working adopted on the main double line was a modified system of the absolute block.

The stations were placed at distances of from ½ to 1 mile apart, and were each provided with a home and starting signal for each direction, both signals being absolute stop signals. The starting signals were erected a little in advance of the front end of the platform, and the home signals 800 feet in rear of the starting signals.

Each station was connected to the one on either side of it by telegraph; and there was a telephone connection between the Traffic Officer's office and the Kashmir Gate, Amphitheatre and Review Ground terminals.

The block section extended from starting signal to starting signal. "Line clear" was not given to a station in rear for any train until the preceding train had left the station giving "line clear" and the rear vehicle had passed the starting signal. Each starting signal was fitted with a lock of the Annet type, so that the signal could not be lowered until the key had been given to the pointsman; and Station Masters were forbidden to order the home signal to be lowered or to admit a train into their station until the key of the starting signal had been returned to their possession. Separate "line clear books" were kept for up and down trains, and a private number was signalled at the end of each "line clear." The "train entering section" report was signalled from a station as soon as a train had left the station and the rear vehicle had passed the starting signal. "In" reports were not signalled to the station in rear as this was considered unnecessary; as the interval between trains was in some cases only 10 minutes, it was imperative to avoid unnecessary signalling as far as possible.

On ordinary occasions trains were worked on the branch lines on the "one engine only" system. On the occasions of the Proclamation Ceremony and the Review, etc., trains were permitted to follow each other on these branches at 10 minutes' interval; with the proviso that all such trains following one another at timed intervals should run in one direction only until all the trains provided in the authorised schedule had arrived complete at the Amphitheatre or Review terminals or, *vice versâ*, had all returned complete to Durbar Road Junction.

On the Polo Ground loop trains were worked on the train staff and ticket system.

Passenger Classes and Fares.

Two classes of passengers were carried, first and second, for which the fares were as below :—

First.	Second.	
*Rs. 0 8 0	0 4 0	from 1. 12. 02 to 27. 12. 02, and from 12. 1. 03 to 17. 1. 03 inclusive.
Rs. 1 0 0	0 8 0	from 28. 12. 02 to 11. 1. 03 inclusive, *i.e.*, during the actual Durbar proceedings.

* 1 *rupee* = 16 *annas*.
1 *anna* = 12 *pies*.
A rupee is fixed at equivalent to 1s. 4*d*., i.e. 15 *rupees* = £1 *sterling*.

Season tickets were also issued as follows :—

(*a*). Special season tickets, available for the whole Durbar period (*i.e.* from 28. 12. 02 to 11. 1. 03 inclusive) and also providing a reserved seat in one of the Proclamation Ceremony and Review Specials, at Rs. 25 each.

(*b*). Ordinary season tickets, available for the same period as above but not available for any special train to the Durbar or Review, at Rs. 10 each.

The total number of tickets issued for passenger traffic were as follows :—

Special season tickets at Rs. 25	769
Ordinary season tickets at Rs. 10	81
Return tickets for Proclamation only at Rs. 10 ...	183
Single tickets for Review at Rs. 3...	193
First class tickets	11,456
Second class tickets	88,024

In addition to the above, special trains were run conveying mutiny veterans, bandsmen, visitors for Bengal Camp, etc., making a total of 12,187 first and 89,916 second class passengers (Appendix C).

If we allow an average of 20 journeys to each of the 850 season ticket holders, we get a grand total of 119,098 passengers carried.

The maximum number of passengers carried on any one day was 1,000 first (exclusive of season ticket holders), and 8,354 second, class passengers ; and the maximum number of tickets issued at any station during one day was 224 first, and 2,657 second, class tickets.

Goods and parcels were not carried by the Light Railway.

Issue, Check and Collection of Tickets.

Each station was provided with two ticket windows, one for first and one for second class passengers ; and ordinary card tickets, available for one single journey any length, were issued at each station. The platforms were enclosed by a wooden fencing, and one entrance only through a turnstile was provided.

British soldiers were employed as Ticket Collectors ; they were posted at the entrance wicket and supplied with a locked and sealed box with a slit in the top. Passengers were not permitted to enter a station until they had given up their tickets to the Ticket Collectors, who immediately dropped the collected tickets into the ticket box.

A British soldier as Platform Sergeant was also appointed at each station, whose duties were to patrol the platform and see that no passenger entered except through the entrance wicket.

To distinguish between first and second class passengers, first class passengers, on delivering up their tickets to the Ticket Collector, were given a cardboard disc labelled first class. These discs were collected by the Guard immediately before starting the train, and were handed back by him to the Platform Sergeant or Ticket Collector.

The system worked satisfactorily as long as the number of passengers at any one station was not excessive ; but during a heavy rush of passengers it was found difficult to distinguish between first and second class passengers without causing some delay. During the Durbar fortnight, when the traffic was exceptionally heavy, it was occasionally found necessary to temporarily suspend second class booking.

The system of collecting tickets from the incoming instead of from the outgoing passengers worked most satisfactorily, and was undoubtedly the most suitable one for the type of railway. To collect tickets from outgoing passengers would have required a larger staff of Ticket Collectors ; and would also have occasioned considerable discomfort to passengers, owing to the unavoidable crowding which would have resulted at the exit gates of the more important terminal stations such as the Amphitheatre and Polo Ground. Further a staff of experienced men for sorting the collected tickets and checking the tickets held by passengers, and also an increased audit staff in the Traffic office and consequently proportionately increased cost of working, would have been unavoidable.

Under the system in force passengers were provided with a separate exit gate at each station, no check was necessary at the exit and all crush was avoided. It was also unnecessary to sort the collected tickets.

Each station was supplied daily with a separate locked and sealed wooden box with a slit in the top, each box being numbered and the station name painted on it. These boxes were locked and sealed in the Traffic Officer's office with a special seal, and the keys were kept locked in the Traffic Officer's cash safe. The boxes containing the previous day's collected tickets were despatched by the first train on each date to the Traffic Officer. The seals of the boxes were examined, the boxes were unlocked, and the tickets of each class were counted daily in the presence of the Traffic Officer and compared with the entries in the daily trains cash book.

A register was kept separately for each station, showing the total number of tickets due, the total number received, and the number of excess or missing tickets, if any, for each date. The total number of excess and missing tickets is given below :—

	Missing.	Excess.
First class	340	230
Second class	1,164	245

The excess tickets were generally due to passengers taking tickets at one station, but entering the train at another.

By subtracting the excess from the missing tickets we find that the total number of non-collected tickets amounted to 110 first and 919 second, which works out to 0·9 per cent. first class and 1·04 per cent. second class.

The British soldiers employed as Ticket Collectors were picked men of good character, who were quick in learning their duties; and it is probable that the number of passengers who travelled without purchasing tickets was very small.

The non-collected tickets moreover do not represent a loss to the railway, as, if they had been used again on any other date, they would have been at once discovered as excess tickets.

The percentage of excess tickets was 2 per cent. first class and only ·26 per cent. second class, the large percentage of excess first class tickets being due to first class passengers purchasing two tickets at the starting station, the return tickets being consequently found as excess in the ticket box of the station from which the return journey was commenced.

Station and Audit Returns.

The returns submitted by stations were simple, and consisted of:—

1. *Daily Trains Cash Book.*—This was in duplicate, and shewed the commencing and closing number of each class of ticket issued, the total number of tickets of each class issued and the total cash earnings for the day, together with any excess or deficiency. The outer portion of the form was torn off and placed in the ticket box with the day's collected tickets.

In order to prevent collusion between the Ticket Collectors and Booking Clerks, a Traffic Inspector was appointed who made periodical checks by taking an additional empty locked and sealed ticket box with him to a certain station. The station ticket box was then removed and the empty box substituted. A sheet of paper was pasted over the slit in the station ticket box, the closing number of each class of ticket noted, and the cash on hand carefully counted. The station box was then taken to the Traffic Officer's office where the tickets were carefully counted, and compared with the tickets due according to the closing numbers and the cash on hand as counted by the Traffic Inspector. Only on one occasion was any discrepancy found, and that was at Durbar Road Junction, when the traffic was exceptionally heavy owing to the rush of passengers to and from the Amphitheatre Branch ; and even in this case the discrepancy was not a large one.

2. *Summary of Daily Trains Cash Book.*—This was a weekly form shewing the total of tickets issued and cash received on each day during the week, and a grand total for the week.

3. *Balance Sheet.*—This was a weekly return shewing the traffic earnings of each station and the amounts remitted to cashier according to the entries in the cash remittance notes.

A balance was made weekly in the Traffic office and a statement prepared, shewing number of train miles run, number of passengers carried and total earnings under each head for each week separately, copies of which are appended at the end of this paper as Appendix C.

System of Cash Remittance.

Cash was remitted daily to the Treasury under a Police guard.

Each station was provided with a cash box and padlock, and the cash receipts of each train were placed in this box immediately a train had left the station. As soon as the last train but one had left each station, the total cash receipts of the day were counted and entered in the cash remittance note, which was in trefoil. The cash was then placed in the station cash bag together with the outerfoils of the cash remittance note, the bags were securely fastened and sealed, and were dropped by the Station Master in person, in presence of the guard, into the travelling cash safe, which was carried daily by the last train and was consigned to the non-commissioned officer in charge of cash at Kashmir Gate Station. The receipts from the last train were remitted with the cash earnings of the following day and were separately entered in the cash remittance note. The guard of the last train was furnished with a cash bag summary, in which each Station Master entered the number of bags put into the travelling cash safe and signed the entry, and the guard signed a receipt for the bags.

On the safe arriving at Kashmir Gate Station it was opened by the non-commissioned officer in charge of cash, in presence of the Station Master on duty, the cashier and the guard. The bags were taken out and compared with the entries in the cash bag summary, and entries were made in a register which was signed by all present. The bags were then placed in the cash safe at Kashmir Gate Station by the non-commissioned officer in charge of cash and the cashier.

The cash safe in Kashmir Gate Station was provided with two locks, the key of one being kept by the non-commissioned officer in charge of cash and that of the other by the cashier.

The cash bags containing the previous day's earning were taken daily to the Treasury by the non-commissioned officer in charge of cash and the cashier, accompanied by a Police escort. On arrival at the Treasury each station bag was opened by the non-commissioned officer in charge of cash, and the contents of each bag were counted separately before him by the counters in the presence of the cashier and Treasury officer. A note book was kept by the cashier and the non-commissioned officer in charge of cash, in which the daily receipts from each station were separately entered; from the contents of these note books, the traffic cash check sheet was filled in, signed by the cashier and non-commissioned officer in charge of cash, and sent daily to the Traffic office, together with the Treasury receipts.

On Sundays the cash bags remained in the cash safe at Kashmir Gate Station under a Police guard.

Base, soldered or light coin, detected at the Treasury, was replaced in the station cash bag in which it was found and taken to the Traffic Officer for inspection; he decided what balance, if any, was to be written off, the remainder being debited to the staff in fault.

This system was found to work most satisfactorily, and no thefts or discrepancies occurred throughout the period that the railway was open for traffic.

Staff.

The staff employed for working the Durbar Light Railway was gradually increased in proportion to the number of trains run. When the railway was opened on the 1st December 1902 only three trains were run each way; this was increased to nine from the 12th December, on which date the Amphitheatre Branch was also opened for traffic, and to over 20 from the 18th.

The staff actually employed at each station at the opening of the railway consisted of six men, *viz.* one Station Master, one Booking Clerk, one Signaller, one Ticket Collector, one Platform Sergeant and one Pointsman, with one Sweeper and one Bhistie in addition at the more important stations.

The running staff consisted of four Guards and one Traffic Inspector.

In addition to the above, arrangements were made with the Assistant Inspector General, Railway Police, to provide an efficient police force, which consisted of three constables at each station and one Deputy Inspector, two Sergeants and one additional constable at Kashmir Gate.

Arrangements were also made with the Paymaster, North-Western Railway, to provide staff for cash arrangements; this consisted of 1 Cashier, 1 Pay Clerk, 2 Counters, 2 Peons.

The staff employed in the Traffic Officer's office was:—1 Chief Clerk and Establishment Clerk, 1 Accountant, 1 Trains Clerk, 1 Record-keeper and Despatcher, 1 Assistant Establishment Clerk, 1 Stores Clerk, 1 General Clerk and 1 Typist.

On and after the 18th December the staff at stations and the running staff were augmented. 1 Assistant Station Master, 1 Signaller and 1 Pointsman were added at each station; and at Durbar Road Junction it was found necessary to post an additional Platform Sergeant and Pointsman. Four extra guards were also appointed from the 20th December.

On the 25th December, as the traffic had become very heavy and the hours of duty of the Platform Sergeants and Ticket Collectors had been extended to nearly 14 hours, additional relief Platform Sergeants and Ticket Collectors were obtained from the Military Department.

The total staff during the Durbar period, when eight stations were opened to traffic and over 40 trains each way were running daily, was as follows:—

8 Traffic Officer's Clerks, 1 Traffic Inspector, 8 Guards, 8 Station Masters, 8 Assistant Station Masters, 8 Booking Clerks, 16 Signallers, 19 Pointsmen, 17 Ticket Collectors, 17 Platform Sergeants, 8 Sweepers, 4 Bhisties, 8 Peons.

The average cost of the staff at each station per day amounted to Rs. 12. 10. 6; and the total cost of the traffic staff, including the pay of the Traffic Officer and office establishment, amounted to Rs. 15,000 approximately.

The staff was gradually reduced from the 12th January 1903 until the railway was closed on the 18th January.

Earnings.

The total traffic earnings amounted to Rs. 68,222 11 0 (Appendix C), out of which a sum of Rs. 19,197. 8. 0 was due to the sale of special season tickets.

An approximate estimate of the cost of the Traffic working is given as Appendix A.

APPENDIX A.

ABSTRACT OF COST OF TRAFFIC WORKING.

	Rs.	a.	p.
Establishment	16,393	15	1
Contingencies	486	1	4
Furniture on loan from North-Western Railway	3,149	1	0
Running room stores	402	0	0
Consumable stores	100	0	0
Advertisement charges	83	1	0
Printing charges	1,707	15	0
Cost of tickets...	4,110	8	0
Locally purchased stores	538	5	6
Total	26,970	14	11

	Rs.	a.	p.	Rs.	a.	p.
Recovered—						
(1). By auction	200	0	0			
(2). By furniture returned to North-Western Railway	3,000	0	0	3,200	0	0
Grand Total...				23,770	14	11

APPENDIX B.

ABSTRACT OF THE COST OF CONSTRUCTING AND WORKING THE DELHI DURBAR LIGHT RAILWAY.

CONSTRUCTION.

		Rs. a. p.	Rs. a. p.	Rs. a. p.
Engineering.	Staff	2,513 8 9		
	Labour charges	7,142 0 0		
	Stores	58,330 3 7		
	Work done by contract.. ...	33,320 6 2 ...	1,01,306 2 6	
Locomotive.	Staff	1,068 0 4		
	Stores...	2,266 15 11 ...	3,335 0 3	
	Carriage charges		11,925 14 0	
			1,16,567 0 9	
	Anticipated credit		45,137 6 0 ...	71,429 10 9

WORKING.

		Rs. a. p.	Rs. a. p.	Rs. a. p.
Traffic.	Staff	15,461 0 0		
	Stores	10,328 4 5		
	Carriage	7,000 0 0 ...	32,789 4 5	
Locomotive.	Staff	4,138 15 2		
	Stores	7,162 6 4		
	Carriage	5,000 0 0 ...	16,301 5 6	
Engineering.	Staff	5,173 15 5		
	Stores	2,180 15 2		
	Carriage	5,000 0 0 ...	12,354 14 7	
	General charges...		1,174 14 6	
			62,620 7 0	
	Anticipated credit		9,394 0 0	
			53,226 7 0	
	Add salary of Engineering and Locomotive staff for February 1903		650 0 0	
	Anticipated debit for Police, say		50 0 0	
	Total expenditure on working			53,926 7 0
	Add dismantling charges			500 0 0
	Grand Total on construction and working			1,25,856 1 9

APPENDIX C.

STATEMENT OF WEEKLY COACHING RECEIPTS OF DELHI DURBAR LIGHT RAILWAY.

		Total No. of Train Miles open.	No. of Passengers carried. First.	No. of Passengers carried. Second.	Total Receipts. Rs.	a.	p.	Total No. of Train Miles run.	Average No. of Passengers carried per Train Mile run, exclusive of Season Ticket-holders.	Receipts per Train Mile. Rs.	Receipts by Sale of Special Season Tickets. Rs.	a.	p.	Receipts by Sale of Ordinary Season Tickets.	Miscellaneous Earnings.			Grand Total. Rs.	a.	p.
Total for week ending	6. 12. 02	8	53	665	192	12	0	144	4·98	1·39	7,352	8	0	190	451	0	0	8,186	4	0
Ditto	13. 12. 02	9·75	159	1,426	433	8	0	326	4·84	1·33	1,575	0	0	20	1	0	0	2,029	8	0
Ditto	20. 12. 02	9·75	275	3,791	1,085	4	0	915	4·44	1·18	2,300	0	0	230	4	4	0	3,619	8	0
Ditto	27. 12. 02	9·75	3,127	24,815	7,767	4	0	1,627	17·17	4·77	5,025	0	0	180	18	6	0	12,990	10	0
Ditto	3. 1. 03	9·75	5,768	37,962	26,344	8	0	2,342	18·67	11·67	2,900	0	0	190	41	4	0	30,475	12	0
Ditto	10. 1. 03	11·75	2,407	15,488	9,186	7	0	2,341	7·64	3·92	45	0	0	—	3	2	0	9,234	9	0
Ditto	17. 1. 03	9·75	398	5,769	1,683	0	0	872	7·07	1·93	—			—	3	8	0	1,686	8	0
Grand Total	..	11·75	12,187	89,916	47,692	11	0	8,567	11·9	5·56	19,197	8	0	810	522	8	0	68,222	11	0

APPENDIX D.

ENGINEERING MANUAL.

NOTE.—*The Durbar Light Railway will be worked under the General Rules for Indian Railways, to which the rules given herein are to be considered as subsidiary.*

PRELIMINARY.

1. For the purposes of maintenance the line will be divided into two Sections.

No. I. Section from Kashmir Gate, up to but not including the Najafgarh canal bridge, with the Kashmir Gate sidings, will be in charge of the Officer Commanding No. 4 Company Bengal Sappers and Miners.

No. II. Section from the Najafgarh canal bridge to the Polo Ground Loop, with branches, will be in charge of the Officer Commanding No. 4 Company Bombay Sappers and Miners.

2. A copy of the General Rules for Indian Railways will be supplied to the Officer in charge of each section who will be required to sign a receipt for the same. Such Officer will be responsible that each man working on the line under his orders has a general knowledge of the rules in so far as they concern his duties, and that all concerned are fully acquainted with the rules given below which apply to the special work on which they are employed.

PERMANENT WAY AND WORKS.

1. The Officer in charge of each section will be responsible for the condition of the permanent way, bridges, buildings and works of all description on his section; and must promptly report to the Special Railway Officer all accidents thereto and defects therein which he may consider likely to interfere with the safe running of trains.

2. The Officer in charge of each section will personally inspect the whole of his section daily; and satisfy himself by frequent cross examination that the men working on the line, gatemen and others,

under his orders are acquainted with their duties and know what to do in case of emergency.

3. Each section is to be divided up into gang lengths as the Officer in charge of the section may consider most convenient, and the point at which one gang length ends and the next begins must be well defined and known to every member of the gangs concerned.

4. Each gang will be in charge of a trustworthy Non-Commissioned Officer or Sapper, hereafter referred to as the ganger, detailed by the Officer in charge of the section.

5. In each gang a man will be appointed as keyman, subordinate to the ganger. It will be his duty to constantly patrol his gang length, tighten up loose fishbolts and keys, examine the line generally and bring to the notice of the ganger any defects which he may observe.

6. The ganger will be responsible for all work undertaken on his length and for the condition of the road, signals, fencing, drains, etc., and the general upkeep of the line and banks.

7. One or more special gangs will be appointed in each section at the discretion of the Officer in charge of the section and will preferably be composed of the trained men lent by the North-Western Railway. The Officer in charge will use them on any part of his section on which he considers extra labour necessary to assist the regular gangs.

8. Each gang is to be provided with the following tools :—

Rail gauge 2′6″	1
Sight boards	3
Spirit level	1
Bars, Shovels, Beaters	as required.
Spanners	1
Keying hammers	1
Red flags	2
Green flags	2
Detonators (fog signal)	6
Hand signal lamp	1

9. In addition to the above each gang should have a small supply of spare permanent way material, which should be kept neatly stacked at a convenient level crossing in charge of the gateman.

10. Each keyman is to be provided with the following :—

Keying hammer	1
Spanner	1
Spare keys	6
Spare fishbolts and nuts	6
Red flag	1
Green flag	1

11. The Officer in charge of the section must constantly satisfy himself that the tools and stores detailed above are in possession of their gangs, and are kept in good order and ready for immediate use.

12. It must be distinctly understood by all concerned that once the line is open for traffic no work of any sort is to be undertaken which will render the line unsafe for traffic, unless the line is first blocked; and no such work shall be performed except on the authority of the Officer in charge of the section, who must himself be present until the line has been again made safe for the passage of trains.

13. Signals will be exhibited by gangmen and others when necessary in the following manner :—

Caution Signal.—A green flag exhibited by day, or a green light by night.

Danger Signal (Stop).—A red flag exhibited by day, or a red light at night; in addition two detonators are to be placed on the line 10 feet apart and 30 yards in advance of the point where such signal is exhibited.

14. The time for effecting repairs, or performing any other work which will involve delay to trains, must be selected so as to interfere as little as possible with the passage of the traffic.

15. When repairing or lifting the line, or performing any other operation which will make it necessary for a train to proceed cautiously, the ganger must :—

(*a*) himself be present at the spot,

(*b*) send a man, on the double line backwards, and on the single line in each direction at least 200 yards, to show a caution signal to the driver of the approaching train, and

(*c*) show another such signal at the site of the operation.

Provided that if the ganger has any doubt as to the line being in a fit state to pass a train at slow speed he must see that a danger signal is shown and that detonators are placed on the line as detailed above.

16. When signalling the flag must be held horizontally well clear of body. The flag not in use is to be kept out of sight.

17. In lifting the permanent way :—

(*a*) no lift will be made of more than two inches at once.

(*b*) every lift must be made so as not to occasion any sudden change of gradient.

(*c*) both rails must be raised equally and at the same time, and

(*d*) the ascent must, on the double line, be made in the direction in which the trains run.

18. Earth or ballast must not be thrown up between the rails higher than rail level, and must be thrown as much as possible on the outside of each line or between the two roads. The rails themselves must be kept quite clear of ballast, earth, gravel or other material.

19. When a train is approaching all men working on the line must *at once* stop work and stand well clear of the road and see that no tools or material are left lying foul of the line and that the rails are clear of earth, stone or ballast.

20. Every member of the staff must fully understand that, owing to the up and down lines on the double line being laid at 8 feet centres only, there is not sufficient room to stand between two trains passing each other, either in or out of stations. Men working on the line should, therefore, on the approach of a train stand clear of both lines and not between the tracks.

21. If any Officer, subordinate or ganger becomes aware that the line is unsafe from any cause whatever, he must proceed to the spot and see that a danger signal is plainly shown and that detonators are placed on the line as detailed above. Such signal to be exhibited, on the double line, 200 yards from the point where the line is unsafe and in the direction from which trains approach, and on the single line, 200 yards in each direction. Provided that, if both lines of the double line are affected, such signal shall be exhibited as for single line, *i.e.*, in each direction.

As soon as possible the matter is to be reported to the Station Masters at the stations on either side of the point where the line is unsafe and to the Officer in charge of the section.

22. If a rail is fractured, a danger signal must be exhibited until it can be renewed or until the following precaution has been taken. If the rail is broken off short the nearest sleeper must be shifted under the fracture so as to take both ends; trains can then run slowly over the rail until it is replaced, which should be done as quickly as possible.

23. In the case of heavy rain each ganger must carefully examine his road and note the action of the water through the culverts, bridges and drains on his length.

Should he see any cause to apprehend danger to the works, he must immediately show the proper signals for trains to proceed with caution or to stop, as necessity may require, and inform the Officer in charge of the section.

24. Each section will be inspected by the Officer in charge himself as soon as possible on the occurrence of heavy rain.

25. No blasting operation will be carried on near the Railway without the permission of the Officer in charge of the section, who will be responsible that proper precautions are taken.

26. In the event of a report being received from a Station Master that any signal is out of adjustment or requires repairs the Officer in charge of the section will at once take steps to have it put right.

27. The condition of all tanks, pumps, water-columns, piping, etc., must be inspected occasionally by a subordinate deputed for the purpose by the Officer in charge of the section, and defects promptly attended to.

28. Spare permanent way material is on no account to be left lying about by the side of the line; it must be collected and neatly stacked at some convenient spot well clear of the line and in charge of an authorised person.

29. It is the duty of every man working on the line to see that the line is kept clear of cattle and of unauthorised persons trespassing on it. In the event of persons refusing to move off the line when warned to do so, or of persons being found in the act of maliciously attempting to damage or obstruct the line, such persons should be handed over to the Station Master at the nearest station with a report of the circumstances of the case.

Level Crossings.

1. All level crossings will be under the charge of the Officer in charge of the section in which they are situated.

2. At important level crossings the gates are to be normally kept open for road traffic. Such gates are to be manned by two or more gatemen as may be necessary.

3. At unimportant level crossings, where the traffic across the line is inconsiderable, the gates (or chains where there are no gates) are to be normally kept locked across the road whilst trains are running, and are only to be opened to allow a vehicle or animals to cross the line. Such gates are to be manned by one or at most two men.

4. After the last train has passed at night and until the first train the next morning is due all gates are to be kept open for road traffic and locked in that position.

5. At gates which are normally open for road traffic the gateman must, on the approach of a train, at once shut the gates across the road and then exhibit an all-right signal to the driver, a green flag by day or a green light by night.

6. At all gates the all-right signal is always to be shown to the driver of an approaching train, provided the gates have been securely fastened across the road and the line is clear; drivers are instructed to stop unless they see such signal.

7. At gates which are normally locked across the road the gateman, before opening the gates for the passage of road traffic, must look up and down the line to assure himself that no train is approaching.

(*a*). When road traffic is approaching from one side only, the gate towards which it is approaching will not be opened until the opposite gate has been opened.

(*b*). When road traffic is approaching from both sides, the gateman will not permit any person or animal to enter upon the line until both gates have been opened.

(*c*). After the gates have been opened for the passage of road traffic the gateman must close them as soon as possible after the road traffic has passed through.

8. All gates are to be fitted with at least one proper gate lamp, so fitted as to show a red light in the direction of approaching trains when the gates are open for the passage of road traffic.

9. Gate lamps are to be lit at dusk and kept burning all night; the gatemen are responsible that they are properly lit and remain so.

10. Where there are double gates with only one signal lamp to each gate, the gate with the signal lamp will not be moved to

allow of the passage of a train until the other gate is shut across the thoroughfare.

11. Every gateman must, when signalling, stand clear of the rails in a position where he can be seen by the driver of an approaching train.

12. If any gate, or the fastening thereof, should get out of order the gateman must immediately report the fact to the Officer in charge of the section.

13. The gateman must see :—

(*a*). That the channel for the flange of the wheels is always clear before the passage of each train.

(*b*). That the rails and way are clear.

(*c*). That rubbish is not allowed to accumulate near his hut or near the level crossing.

14. Should there be any obstruction on the line within the sight or knowledge of the gateman, he must show danger signals and take any other necessary steps to warn the guards and drivers of approaching trains in order to prevent an accident.

15. The gateman must take particular notice of each train, and if anything be wrong with any train he must show a danger signal to the guard and driver.

16. Constant vigilance is required on the part of the gateman, and one man at least at each gate must be on the look out *at all times* so long as trains are running.

17. Every gateman must as far as possible prevent any trespassing on the Railway, and must as soon as possible report every case of trespass to the Officer in charge of the section.

18. No gateman shall leave his gate unless another gateman has arrived to take charge of it.

19. At the Rajpur Road level crossing fixed dwarf semaphore signals are provided in each direction to control approaching trains. The gate will be in charge of a British N.C.O. or private under the orders of the Officer in charge of the section. It will be his duty to see that the road traffic is kept under proper control and that the above rules are correctly carried out by the gatemen under his orders. He will not leave the gate during his tour of duty under any pretext.

20. On the approach of a train at the Rajpur Road level crossing the gates are to be at once closed and fastened across the road, after which the dwarf signal controlling the approaching train will

be lowered ; the N.C.O. in charge is responsible that such signal is at once put to danger after the passage of the train and that it remains so. He will also see that a sharp look out is kept for up trains from Mori Gate Station.

BALLAST TRAINS.

1. If the Officer in charge of a section wishes to run a ballast train he must consult the Traffic Officer who, provided the state of the traffic admits of it, will arrange the times at which the train is to run and issue the necessary instructions to the Traffic and Locomotive Staff.

2. Each ballast train is to be accompanied by a guard.

3. Ballast trains must work on the Absolute Block System as laid down in the Rules for working.

4. Ballast trains are not on any account to shunt back in the wrong direction on the double line, but must run round the complete circle in the same way as passenger trains.

5. Officers in charge of sections for whom ballast trains are run are responsible that a sufficient number of coolies accompany the train and that the work is done as expeditiously as possible and that no delay is caused to passenger trains.

6. The guard of the train is responsible that the line is left clear of earth, stone or other material after the ballast train stops work at any point, and that on completion of its work the train is returned to Kashmir Gate and shunted clear of the Main Line.

MATERIAL TROLLIES.

1. All material trollies are to be kept at a station, well clear of the line, with the wheels securely fastened with a chain and padlock when not in use.

2. No material trolly will be placed on the line without the written authority of the Officer in charge of the section.

3. Before a material trolly is placed on the line, line clear must be obtained for it in exactly the same way as for a passenger train (see Rules for working).

4. Line clear messages for trollies must be recorded in the train message books.

5. On the double line the trolly is to be kept to the line for which line clear has been obtained and is not to be taken off the line, except in case of emergency, at any other place than the

station to, or the station from which, line clear has been obtained. Under no circumstances must a trolly for which line clear has been obtained on the up line be shifted to the down line, or *vice versâ*.

6. Each material trolly must be accompanied by a responsible subordinate specially authorized by the Officer in charge of the section to use the trolly.

7. Each material trolly must be accompanied by a sufficient number of men to remove it from the rails promptly and to properly control its movements on the grades.

8. Every material trolly must carry one red and one green flag, one hand lamp ready for use, and one padlock and chain.

9. The person in charge of the trolly must under all circumstances be held responsible for its use and for knowing when trains are due ; he must obtain from the Station Master before starting a memo. in writing, giving the time at which his trolly should be removed either at that station or the next in order to avoid causing delay to trains. In all cases a trolly, as soon as possible on the completion of the work, is to be returned to the nearest station, where its arrival should be reported to the Station Master and the trolly removed clear of the line and the wheels securely locked.

No material trolly shall be attached to a train.

10. The above rules apply also to goods wagons or trucks pushed by men.

Light Trollies.

1. No trolly will be placed on the line except under the charge of an officer specially authorized to use a trolly on the Durbar Light Railway by the Special Railway Officer.

2. No person not in possession of such authority will be allowed to travel on a trolly unless he is accompanied by the Officer authorized to use the trolly.

3. An officer authorized to use a light trolly must under all circumstances be held responsible for its use and for knowing what trains are due; and, as a special precaution against accidents from light engines, etc., must, when passing a station, enquire from the Station Master whether the line is clear and whether a train is expected in either direction.

4. No trolly is to be run on the line unless it is accompanied by enough men to readily lift it off the rails, and in no case will the number be less than three.

5. When it is not possible to obtain a clear view of the line in

front and rear by reason of curves, cuttings, buildings, etc., a trolly will be preceded, or followed, or both, by a man carrying a red flag at a distance of 200 yards.

6. When not in use a trolly must be placed well clear of the line with the wheels secured by a chain and padlock.

7. Each light trolly must exhibit a red flag on a staff by day or a red light at night; and must carry red and green flags, hand signal lamp, and padlock and chain.

8. A trolly meeting a train must be removed in good time so as to prevent any delay to the train.

9. No light trolly shall be attached to a train.

Line Blocked by Engineering Department.

1. Except in cases of urgent necessity, the arrangements under which the line between stations is to be blocked should be discussed by the Officer in charge of the section with the Traffic Officer at as early a date as possible before the contemplated block; and it should, at the same time, be settled by which official of the Engineering Department the block will be removed.

(*a*). After an agreement has been come to, the Traffic Officer will block the line as required by a joint message to all concerned, detailing between which stations the line is to be blocked, which line is to be blocked, after what trains block will commence, and which trains, if any, are to be cancelled, etc., and also stating by whom the block will be removed. This telegram must be acknowledged.

2. When removing the block, the Engineering Department official responsible will send a joint telegram to the Station Masters on each side of the section that has been blocked, advising them that the block has been removed and asking for an acknowledgment.

The message should be worded as follows :—

From	*To*
O.C.I.,	S.Ms.,
M.T.	M.T. and F.S.

No. 6—Block on up line between M.T. and F.S. removed at hrs. mts.

(*a*). This message would be dealt with by the transmitting station, as in the case of the "Block message," and be acknowledged by a joint message by the receiving station in the same way ; the acknowledgment of the receiving station, with signature of the Station Master of the transmitting station on the back of the acknowledgment, being sent to the Engineering official who removed the block. The acknowledgment would be worded as follows :—

From	*To*
S.M.,	O.C.I. & S.M.,
F.S.	M.T.

No. 26—Your No. 6 received at hours minutes.

(*b*). If the person named by Traffic Officer is for any reason unable to remove the block, this may be done by any other authorized Engineering official, the Engineering Department taking all responsibility for the action of such official.

3. When an engine or train is ordered to proceed on to a blocked section, a "Permission to proceed" form T.S. 128 or 129 must be issued. The Engineering official, who orders that such engine or trains may run, must give the Station Master a written authority detailing :—

1st.—Up to what mileage train can proceed.

2nd.—Whether it is to return to the starting station or not, and if so at what time.

3rd.—Whether to run on to the next station, and if so by what time.

4th.—If a subsequent train may follow, in which case the information must detail mileage each is to work to and the time of return of each or either train.

On receipt of necessary information, the Station Master will issue a "Permission to proceed without line clear" form, with details properly entered.

(*a*). In all cases the Engineering Department official will be responsible for the protection of trains running on to, or over, a blocked section.

4. In emergent cases, when the line has to be blocked without previous reference to the Traffic Officer, the following procedure as to advising stations must be followed, copies of block message, etc., being sent to the Officer in charge of the section and Traffic Officer

by the Engineering official who blocks the line and removes the block.

(*a*). The Engineering Department official, *i.e.*, the Officer in charge of the section or the subordinate who blocks the line, will issue a joint telegram to the Station Master on each side of the section to be blocked, advising them of the time from which the block is to be imposed and asking for an acknowledgment from each, as in the following example :—

From	*To*
O.C.I., M.T.	S.Ms., M.T. and F.S.

No. 4 Down Line between M.T. and F.S. will be blocked after arrival of 9 Up at M.T. acknowledge.

or

No. 4 Up Line between M.T. and F.S. will be blocked from 14 hours Acknowledge.

(*b*). The Station Master receiving this message for transmission will sign for it, noting the time of receipt, and will signal the message to the "Station to." The latter will acknowledge receipt by a joint message addressed to the Engineering Department official and the Station Master of the transmitting station, as shown in the following examples :—

From	*To*
S.M., F.S.	O.C.I. & S.M., M.T.

No. 24.—Your No. 4 received at hrs. mts. Down line between this and M.T. will be blocked after arrival of 9 up at M.T.

or

No. 24.—Your No. 4 received at hrs. mts. Up line is blocked between this and M.T. from 14 hours.

(*b*). On receipt of this message, the Station Master of the station from which the block message was transmitted will hand a copy to the Engineering Department official to whom addressed ; but before doing so, the Station Master must sign his name at the back of the message and enter the time of his having done so.

The section will be considered as blocked from the time entered on the block message and no line clear or caution message must be given for any train to run over the blocked section after that time until the block is removed.

5. Block will be removed as shown in Rule 2 above. The Engineering official when sending message removing block should quote No. of his telegram imposing the block.

6. When blocking the line on the double line it must be distinctly stated whether the up line or the down line or both are to be blocked. The same procedure being adopted when removing the block.

7. When it has been arranged to block the line and the official of the Engineering Department, under whom the work on the blocked section of the line is to be carried on, finds that one or more trains are late which should have passed before the block was put on, he may, if he finds he can delay the work and blocking of the line to allow them to pass, remove the block under Rule 2 above and reimpose it again as soon as the late trains have passed, advising Station Master on either side and the Traffic Officer.

MISCELLANEOUS.

Telegraph and Telephone Arrangements.

1. Each station is in telegraphic communication with the station on either side of it.

There is no through telegraph line.

Kashmir Gate, Amphitheatre and Review Ground are in telephonic communication with the office of the Traffic Officer, where there is an exchange.

2. For the purposes of Service telegrams the following abbreviations will be used :—

Special Railway Officer	S.R.O.
Traffic Officer	T.O.
Officer in charge No. I. Section	O.C. 1.
Officer in charge No. II. Section	O.C. 2.
Loco. Foreman	F.O.
Supervisor	S.P.

3. Subordinates not referred to above must telegraph their names.

4. The use of the wires is to be restricted as much as possible.

NOTE.—*The greater part of the above Report, except Appendix D, was originally printed as Technical Paper No.* 131, *Construction Branch, Public Works Department (Railways), India.*

LIST OF PLATES.

PAPER VI.

NOTES ON PLATELAYING ON LIGHT RAILWAYS

BY NATIVE MILITARY LABOUR IN INDIA.

WITH SOME NOTES ON BLASTING, EXCAVATION, DETERMINATION OF RATES, AND SAFEGUARDING OF RIFLES.

BY

MAJOR U. W. EVANS, R.E.,

Q.O. Madras Sappers and Miners.

CONTENTS.

PLATELAYING ON LIGHT RAILWAYS.

PART I.—PLATELAYING ON THE KHUSHALGARH-KOHAT-THAL RAILWAY, N.W. FRONTIER, INDIA.

DURING the cold weather of 1901—1902 the following Native Troops were employed on the construction of the 2′ 6″ Railway between Khushalgarh and Kohat:—

No. 1 Company Bengal Sappers and Miners.
No. 5 " " " "
No. 6 " " " "
No. 1 Company Q.O. Madras Sappers and Miners.
No. 5 " " " " "
28th Bombay Pioneers.
21st Madras Pioneers.

FORMATION.

The line ran for about ten miles at an unvarying gradient of $\frac{1}{83}$ and thence at easier grades into Kohat.

The curves were all very easy, up to Kohat, I think none sharper than a radius of 1,200 feet.

Owing, however, to certain bridges and cuttings not having been completed by the time the platelaying reached them, it was necessary to put in six diversions between Khushalgarh and Kohat. Diversions.

The gradient on these was permitted to be $\frac{1}{30}$; indeed, owing to a curve on one of them, in one place there was the equivalent of a grade of $\frac{1}{25}$.

All but one of these diversions had easy entry and exit curves and were short, so that once the drivers got to know them they could rush them.

Bridges.

Besides brick and stone arches there were many openings spanned by 6ft., 12ft. and 15ft. girders and a good many 40-footers.

The 6, 12 and 15 foot spans were generally rivetted up complete with cross bracing, with sleepers bolted on by fang bolts, and were then slipped into their place on rails. Rivetting is a troublesome job, and ordinary smiths do not learn it for a week or so. After a week's practice the smiths of a Sapper company will do very fair work, but at first probably all rivets in difficult places would have to be cut out and re-made. The only points to be specially noted are that the rivets must be really hot and that the men must work very quickly so as not to lose heat.

With larger girders the bracing and sleepers have to be put on after erection, and the very greatest care is necessary that everything shall be previously fitted and marked. Everything must be marked to match the place it is to go.

The girders must be marked on the ends "up" and "down" or "E" and "W," and on the sides "Right" and "Left," and with the number of the span.

The bridge sleepers must be numbered on one end with the span number and on the other with their own consecutive number on the span.

The bracing must be marked similarly on each piece; it will not do to bundle the bracing of a whole span and simply mark the outside, for if a bundle breaks open much trouble ensues.

The 40ft. and 60ft. spans were easily erected with derricks and winches.

Whenever, on 6ft., 8ft. and 10ft. openings, the girders were not ready, the line was run over on temporary bridges of rails. A very handy formula for this purpose is:—

Safe moment of resistance in inch tons = weight of rail in lbs. per yard $\times \dfrac{\text{depth of rail in inches}}{5 \cdot 5''}$.

Of course considerations of deflection forbid the use of this for longer gaps.

Permanent Way.

Rails.

The rails used from Khushalgarh to Kohat were 35lb. ones, 24ft. long, spiked to 9 deodar sleepers, spaced as in *Fig.* 1.

It should be remembered that rails vary in length as much as $\frac{7}{8}$ inch.

The fish-bolts were square headed with round shanks, the nuts being hexagonal.

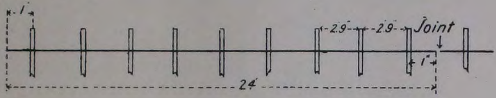


Fig. 1.

The fish-plates were recessed so as to receive the square heads of the bolts and keep them from turning (*Fig.* 2.)

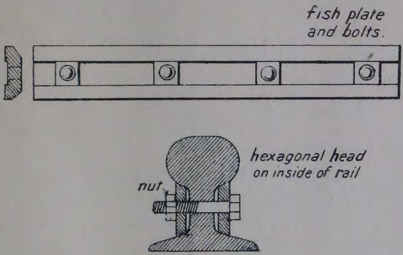


Fig. 2.

This shape of bolt gives much more trouble than one with a square or feathered shank. The head constantly slipped in the fish-plate when tightening up, and two spanner men were required when one should be enough.

The spikes require no remarks. The auger holes for spikes in soft deodar sleepers should be smaller than those for the same spike in pinkadoo or teak or other hard woods, viz. :—for $\frac{7}{8}''$ spike in deodar a $\frac{3}{4}''$ auger, for the same in pinkadoo a $\frac{7}{8}''$ auger.

Bolts come out of store covered with a preserving composition, and the nuts will not run at all. They must be soaked in a mixture of linseed and kerosene oils for 24 hours, and then run down and made properly free. This can be best done by rigging up a "Platelayer's Friend," a sort of rough vice, and freeing the nuts with a spanner (*Fig.* 3). One man can thus in 8 hours prepare 40 to 50 bolts for 35lb. rails, and more of smaller sizes. It is only necessary to run down with a spanner the bolts used in skeleton linking, *i.e.*, half the bolts; these must, after running down, be kept in separate marked boxes. The other bolts need only be soaked.

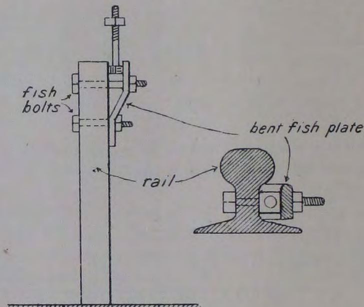


Fig. 3.

Sleepers.

Sleepers may be bored beforehand; but of course great care must be taken to keep the gauge. By completing the augering beforehand one saves all the augerers for other jobs during platelaying.

One man can bore 66 feet of $\frac{5}{8}$-inch holes in deodar in 8 hours, *i.e.*, fifty 4-inch sleepers.

A gauge must be made by which to mark the work for each augerer; and short lengths of rail (about 4″ long), by which to space the holes, should be cut.

The sleepers are recessed at each end to give a cant to the rails to suit the coning of the wheels, a slope of about $\frac{1}{20}$. This recessing should be so done that the inner edge of the cut will be about 2″ clear of the point where the inner edge of the lower flange will come (*Fig.* 4). If the recess is cut exact to gauge the platelayers will depend on it rather than on their own gauges.

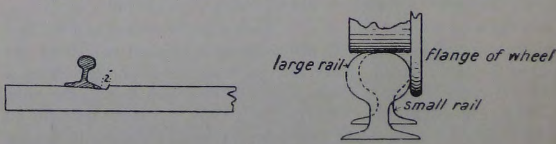
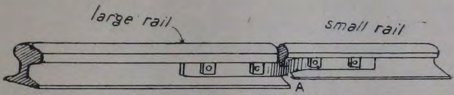


Fig. 4.

It should be remembered that if it becomes necessary to use a rail of different weight for any distance—on diversions we used 41 lbs. and 21 lbs. rails to save the 35 lbs. stock—sleepers bored for the normal rail will not do, as the feet are of different widths; fresh holes must be bored. Also where the change occurs a compound fish-plate must be used (*Fig.* 5).



Side view of compound fish plate.

Fig. 5.

From the preceding it will be clear that, before commencing platelaying, the following must be arranged for:—

(1) Oiling and freeing bolts;

(2) Adzing sleepers to cant rails;

(3) Boring sleepers. (If there are plenty of men for platelaying, of course it will not be necessary to bore beforehand.)

(4) If ballast has not been laid and levelled, a party must be kept ahead to roughly level the formation and provide 6″ or so of packing earth.

(5) All girders and erecting plant must be got ready in time.

(6) The despatch of material in suitable quantities at convenient times must be arranged.

(7) All compound fish-plates, cut rails, etc., must be foreseen, the latter to be plainly marked with paint.

(8) The foreman platelayer must be provided with a diagram of curves, distances, culverts, etc., so that he may be able to demand material correctly.

(9) Provision of pumps, tanks, hose, sleepers, etc., for temporary watering places.

Construction Trains.

New engines on new ill-packed roads will only give about $\frac{2}{3}$ their guaranteed tractive force. Under the same circumstances putting on two engines does not nearly double the available tractive force; in fact, for some weeks, two engines will only furnish the tractive force of one. (Of course each engine is really exerting its whole tractive force; but unregistered grades due to sags, hogs and soft places, bad driving, etc., reduce the apparent tractive force).

of line, and should complete a road on which trains can run at 15 miles per hour for a week or so without maintenance.

The tasks of spreading, linking and material gangs can first be described, and afterwards those of packing and lifting. The following tables show the detail of duties and tools.

Spreading and Linking.

Detail of Parties.

As it was wished on the K.K.T. Railway to instruct the Sappers in as much detail as possible, two Companies were told off in spreading and linking parties, similar to one another, down each side of the line (*Fig.* 6).

Fig. 6.

It would, however, be better to keep companies to separate tasks, as is shown in the table; in this way men do not get mixed up under strange N.C.O.'s.

Parties Spreading and Linking.

Duty.	British N.C.O.	Native Officer.	Native N.C.O.	Sappers.	
1. Spreading Sleepers	—	—	1	15	
2. Numbering Sleepers	—	—	1	—	
3. Augerers.......................	—	—	1	36	
4. Log Line.......................	—	1	—	—	
5. Distributing Fishplates ...	—	—	—	2, light work	
6. Rail Spreaders	—	—	1	16, at 4 men to a rail	
7. Skeleton Linkers	—	—	1	8	
8. assist. Skel. Linkers and inserting Expansion Iron	—	—	—	4	One Company.
9. Spacing Rails..................	—	1	—	—	
10. Chalking Leading Rail ..	1	—	—	—	
11. T Square	—	—	1	—	
12. Distributing Spikes	—	—	—	4, light work	
13. Watching Lead..............	1	—	—	—	
14. Skeleton Spikers	—	—	—	12	
15. Gauger	1	—	—	—	
16. Small Stores Trolly	—	—	1	2, Smith and Carpenter	
17. Distributing 2nd Bolts ...	—	—	—	2, light work	
18. Second Bolters	—	—	—	16	
19. Taking out Expansion Iron and giving to 8	—	—	—	1	One Company.
20. Second Spikers	—	—	—	24	
21. Squaring Sleepers............	—	—	1	2	
22. Rough Straightening	1	—	1	4	
23. Trollies	—	1	2	40	

Tools for Parties Spreading and Linking.

Crows	25	Rachet braces	4	Tommy bars ... (For girder erection.)	6
Wooden purchase blocks	20	Bits for do.	12	3″ rope, 14 fms. (For girder erection.)	20
Spiking hammers ...	25	Oil and Chalk		Plumb bob ... (For girder erection.)	1
Spare helves for hammers	50	Expansion Irons ...	50	50′ tape ... ... (For girder erection.)	1
Sledge hammer... ...	1	Augers	60	Saws 24″	2
Gauges	12	Wrenches	36	Adzes	4
Cold Sets	4	Bolt head caps (to keep round-shanked fish bolts from turning)	12	Cold chisels	4
Flags, red	4	Monkey wrenches ...	2	Hammers, hand, smith's	4
,, green	2			Jumpers	15
				Forge for welding rods of points and crossings	1

Taking the preceding list of parties in detail :—

Skeleton Line.

1. *Spreading Sleepers.*—Bring up and, under the direction of their N.C.O., lay the sleepers down roughly to the alignment and roughly spaced.

2. *Numbering Sleepers.*—An N.C.O. with chalk numbers the sleepers 1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2, 3, 4, 5, etc., etc. This ensures the correct number of sleepers being placed under each rail length, 1 and 9 near the joints; it also affords a check on bad work, as the same auger man or spiker always works on sleepers bearing the same number.

3. *Augerers.*—As soon as the sleepers are spread the augerers set to work. As already explained one man can bore about 66 feet of $\frac{5}{8}''$ holes, or 50 sleepers (4″), in eight hours. There is little to note except that the holes should be vertical, that no downward pressure should be exerted on the auger, and that the men should be very careful of the points.

The N.C.O. is provided with a gauge and with a short length of rail, and marks the places for the auger holes with a pencil.

4. *Log Line.*—A 100-foot log line is laid along the centre (or side) line of pegs, over the sleepers. Keeping the rails parallel to this ensures the linkers keeping the alignment, and saves bent fish-plates, kinks, and loss of expansion. It is clear that if the line is put down anyhow (as in *Fig.* 7), to get it straight by barring over the kinks will close the expansion on one side or other.

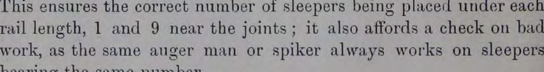


Fig. 7.

5. *Distributing Fish-plates.*—Two old or weakly men place a pair of fish-plates where each joint will be. They get them from the small store trolly, where they are bundled by stout wire passed through the bolt-holes, the wire having to be cut with a cold chisel.

6. *Rail Spreaders.*—Bring up rails and lay them down outside the sleepers (*Fig.* 8).

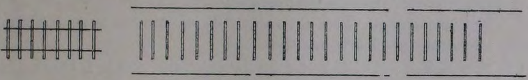


Fig. 8.

7 and 8. *Skeleton Linkers.*—Four men to each rail, receive one fish-plate with two oiled bolts in it (*Fig.* 9) from the assistants, place the rails butting against the expansion iron, put on the outer fish-plate and screw up the nuts hand tight. Then they double forward to the next joint.

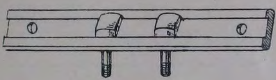


Fig. 9.

The *Assistants* carry the oiled bolts in a haversack or small box with a handle to it.

9. *Spacing Rails.*—Before commencing to fish the next joint the *Rail spacer* sees that the rail which has just been linked is moved laterally to its correct distance (in this case 15″) from the log line. Were the rail lying as *a b* (*Fig.* 10) after the joint had been fished, the Rail spacer would move it to *a*B before allowing the next rail to be linked.

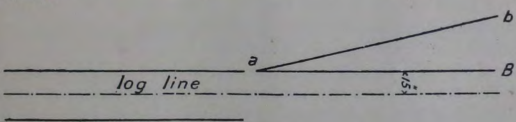


Fig. 10.

10 and 11. *Chalking Leading Rail and Squaring.*—The places for the sleepers must be chalked by a British N.C.O. with a gauge so marked that the sleepers may come 12″ from the ends and 2′ 9″ apart (centre to centre) elsewhere (*Fig.* 1); another N.C.O. with a T square *T squares* across to the other rail.

12. *Distributing Spikes.*—Four spikes are laid on each sleeper.

13. *Watching Lead.*—As on curves (and sometimes even on the straight) the inner rail advances on the outer, it is necessary, as soon as the creep exceeds half the difference in length between a cut and an uncut rail, to put in a cut rail in order to keep the joints square.

A British N.C.O. with a T square watches this and calls for a cut rail when necessary. The cut rails will of course have been got ready and sent out clearly marked.

On the K.K.T. Railway the 35-lb. cut rails were, I think, $3\frac{1}{2}''$ shorter than the others, as this was the distance between centres of bolt-holes. The rails were cut at each end between the bolt-holes, and new holes bored (*Fig.* 11).

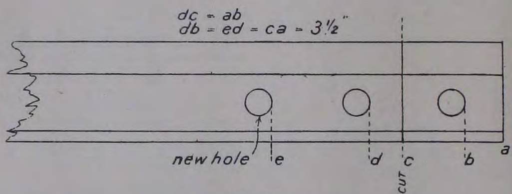


Fig. 11.

14. *Skeleton Spikers.*—Spike sleepers 1, 5 and 9. Two men, with a spiking hammer, a crowbar and a wooden purchase block, form a party. The man with the crow lifts up the sleeper against the foot of the rail while the hammer man drives the spike.

In spiking near a joint, care should be taken not to jar out the expansion iron; the hammer man should keep his foot on it.

It is not easy, though very necessary, to drive the spikes square; the first tap or two of the hammer decides the matter, and so the spike should be held and tapped gently till it has started square and it may then be driven hard. If it then goes diamond it must be turned with the split end of the crowbar (*Fig.* 12).

The spikers on one rail, it matters not which so long as it is adhered to, are provided with a gauge; and before driving fully they put it on. Then, by driving outer or inner spike first, small errors in the gauging can be corrected. I believe that in driving you can make a difference of half-an-inch in the gauge. If any slack gauge is required on account of curves the gauger N.C.O. should know of it.

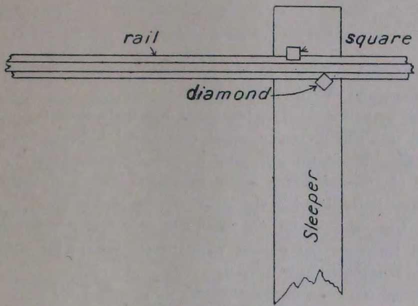


Fig. 12.

To keep sleepers tight so that they will not rack, the spikes must be driven as in *Fig.* 13, and never as in *Fig.* 14.

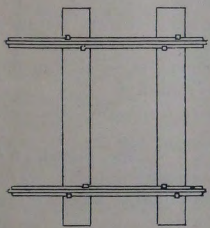


Fig. 13.

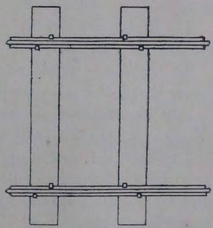


Fig. 14.

15. *Gauger.*—With the skeleton spikers should be a British N.C.O. to watch the gauging and see that it is always done from one side.

16. Just behind the skeleton spikers comes the *Small Stores Trolly*, containing fish-bolts, plates, spikes, a platelayer's friend, oil, etc., etc.

So far the line is a skeleton one, roughly parallel to the log line, is fished with only two bolts, and spiked to only three sleepers. It will suffice to bring up trollies and an engine can come over it very slowly. There is no object in keeping the skeleton linking more than four or five lengths ahead of the full linking.

Full Linking.

The next parties complete the road with second fish-bolts, tighten up and also spike the other six sleepers.

17. *Bolt Distributors.*—Lay two bolts and nuts at each joint. They must not use the specially oiled and freed bolts of the skeleton linkers; they distribute bolts that have been soaked only.

18 and 19. *Second Bolters.*—Put in second bolts and tighten them and the first bolts, leaving the heads square and neat.

About here should be the man *taking out Expansion Irons* and returning them to the person who inserts them; he ought to be about five lengths from rail-head.

20. *Second Spikers.*—Spike sleepers 2, 3, 4, 6, 7, 8.

21. *Squaring Sleepers.*—A N.C.O. and two men, with crowbar, spiking hammer and a block of wood (to place against sleeper so that the hammer may do no damage in knocking square), go over all the sleepers, square any that are crooked, replace split ones, drive or square bad spikes, etc., and finally make a chalk mark to show that they have passed each several sleeper as correct.

22. *Rough Straighteners.*—Bar the line roughly straight, and pack up any very bad places so that the material train may come on.

23. *Trollies.*—Lastly come the trollies running material from the heap, where the train was unloaded, to the spreaders.

The instructions in *Instruction in Military Engineering*, Part VI. (Railways), are full on this subject.

The book, in describing the laying of a 2′ 6″ line, provides for keeping an engine at rail-head following up with material; this I believe is quite impracticable as a rule; difficulties of water for one thing would prevent it.

The general procedure is to unload the material at once at the most advanced spot the engine can get to, and then send the train back. The platelayers can use with advantage as many cutting trollies as they are ever likely to get, and these they should supplement with non-cutting ordinary trollies to such a number that they can load the whole contents of the train up. Then with strong trolly parties the length of lead from place of unloading train to rail-head (*i.e.*, after spreading) does not matter. The parties must be strong, for the work is hard.

The supply of material in manageable quantities is important. On the K.K.T. Railway $\frac{3}{8}$ mile of material was brought up in a train of 18 trucks. The platelayer gangs, even though the trolly parties sometimes fell to 24 men, could work at the rate of a mile in seven hours, with about 12 trollies. Supply of Material.

The effect of increased lead was shown on one occasion when $\frac{3}{4}$ mile was delivered in one spot and, working hard, the same parties only did 160 lengths (about $\frac{3}{4}$ mile) in eight hours.

In conclusion I would emphasise the fact that the ruling factor in the rate of platelaying is the supply of material. The best Officers and N.C.O.'s should be employed on this. An Officer or good N.C.O. should travel back with each empty train and come out to rail-head with the next material; he can count the stores on the way.

At rail-head the platelaying Officer should keep a ledger in which to enter up the stores as they come out. It is not convenient to trust to the counterfoils of the Guard's way bills.

If material is supplied properly in lengths of $\frac{3}{8}$ mile, the parties already detailed should link in $1\frac{1}{2}$ miles per day of eight hours after a week's practice, provided there are no checks for culverts, bridges, etc., etc. Rate of Platelaying.

I have nothing to add to what is to be found in the text-book. I would only mention that it is necessary to be careful about taking out rails from an already laid portion. If the fish-plates are tight all expansion or contraction for several lengths may take place towards or away from the gap; and, if the fish-plates work loose or the sleepers take a tighter grip on the formation, it is quite possible that the gap may never come back to its original length. Therefore, before taking out rails to lay in a crossing or points, you should loosen bolts and fish-plates for several lengths. Points and Crossings, Curves, etc.

Time can be saved if points and crossings be got out a day or two before they are to be laid, and cut and laid out ready to fit in their place.

Packing and Lifting.

The next operation is that of lifting the 2′ 6″ road on wooden sleepers, to an alignment safe for running, and packing with earth.

To effect this the linkers on the K.K.T. Railway were followed by another company of about 100 rank and file, lifting, packing and straightening.

It must be understood that no attempt is made at first to get the line up to its true final level; that is a matter of many months.

The first parties only take out short hogs and sags, pack every sleeper firmly, and true all straights and curves over a distance of about 3 miles from rail-head.

The men worked in their own Sections under their Section N.C.O.s. The allotment of men to jobs was as follows :—

1. *Six Sections* under a Native Officer. Lifting, packing, roughly trueing curves and straights; each Section 12 lengths at a time.

2. *Straightening Party.*—1 N.C.O. and 3 men under a Permanent Way Inspector. Trueing straights and curves, using jimcrow where necessary.

3. *One Section.* Packing and lifting joints which have sunk under traffic, about 1 mile behind other Sections.

4. *One Section* with a British N.C.O. or Native Officer. Taking out any new bad places, and generally finishing up curves, straights, etc.

Tools.

Each Section requires about the same tools, the strength being about 2 N.C.O.s and 10 to 13 men.

Bars, crow, small; or jumpers	4
Shovels	8
Beaters	8
Picks	2
Straight-edge	1
Level, spirit...	1
Flags, red	1
Flags, green	1
Block of wood for purchase	1

A jimcrow will also be required, and should be used under the direction of the Permanent Way Inspector in charge of the lifting and packing.

Packing Material.—A bed of soft earth or sand, 7 feet wide and 6 inches deep, was sufficient for packing.

Detail of Parties.

Various details are given in *I.M.E.*, Part VI., under the head of Maintenance; I will describe how we worked on the K.K.T. Railway.

Centre pegs were put in by the Sub-Divisional Officers at 100-foot intervals on curves and at 200 feet or 500 feet on straights. Whenever the distance between pegs is over 100 feet, it saves much trouble if the Officer in charge of platelaying gangs puts in other pegs at 100-foot intervals. It is not that they are absolutely necessary, indeed the final trueing of the line when it is clear, and a view can be got along it, is easier without pegs. But when the line is crowded with men, with linkers, spreaders, trollies, etc., etc., the

N.C.O.s in charge of Sections cannot, without pegs, get the line even approximately true.

I will now describe the duties of the parties seriatim.

1. *Six Sections*, each under a N.C.O., lifting, packing and roughly trueing straights and curves.

The Native Officer in charge gives each Section about 12 lengths to do; as soon as this is finished the Section moves forward to a fresh 12 lengths.

The Commander of the Section proceeds as follows:—

He finds the line as shown at A in *Fig.* 15.

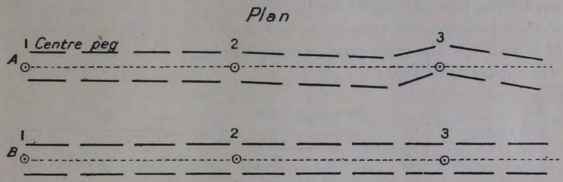


Fig. 15.

(i.). He bars over the rails at 1 and 2 pickets so that pickets shall be in centre. Then he sends two men with a bar each and roughly straightens the line—as shown at B—between pegs 1 and 2, *i.e.*, for about four rail lengths. The N.C.O. stands at 1 or 2 and thence directs the bar men what to do.

(ii.). Next he lies down on his stomach, with his eye just inside one of the rails, the right or left as he may choose, and looking along he decides what joints to raise or lower. He will find something like C_1 or C_2 (*Fig.* 16), and he must improve it till it resembles D_1 or D_2.

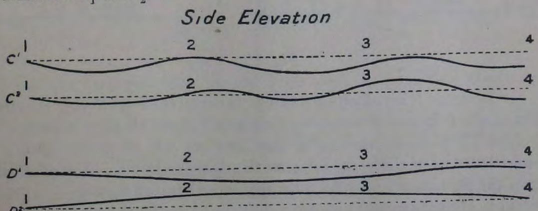


Fig. 16.

Say he finds matters as shown at C_2, and determines to bring to D_2. He has to bring up the four rail lengths between 1 and 2 pegs (*Fig.* 17).

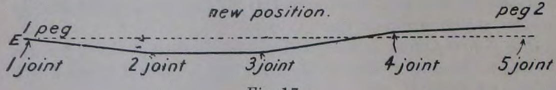


Fig. 17.

He sends a man with a bar to lift No. 5 joint to such a height as shall bring the 12 lengths to the shape D_2; two men with beaters at once pack the two sleepers (called guard sleepers) on either side of the joint. The same process is repeated at joint 4, when the line will appear as in *Fig.* 18.

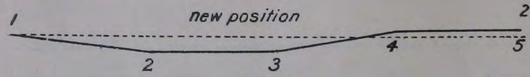


Fig. 18.

The process is repeated at the other joints, and the remaining men with beaters pack the other seven sleepers of each rail.

(iii.). Next the N.C.O. places his straight-edge across the line B at 1 and 2 with his level on top, and brings the other rail to the same level on the straight, or on a curve to such less level as is necessary (*Fig.* 19).

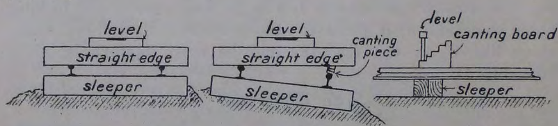


Fig. 19.

(iv.). Again lying down, he brings this rail into the proper line by lifting the joints as already explained, and packs all the sleepers.

(v.). These four rail lengths can now be put nicely straight (or curved) between the pegs, for now the sleepers, having been packed, grip the formation and will remain where they are barred.

(vi.). He then treats his other eight rail lengths the same way.

(vii.). Finally he sends off all the men (except two bar-men and two beater men) under the next senior to a fresh task of 12 lengths, while he himself puts the finishing touches on the 12 lengths he is completing.

He should go back four lengths or so from the joint where he began and have a good look, and then bar true throughout and pack any loose places. Loose sleepers are found by tapping with head of a beater.

The small sight boards were never used, and are only required when there is loose earth on the rails.

2. *Straightening Party.*—This party was usually accompanied by the platelayer British N.C.O., or Permanent Way Inspector, for here he could note faults and was close enough to go forward and correct them, and this was the place where it was most convenient to use the jimcrow on curves or on bent fish-plates.

Trueing long straights is not at all easy. To do so three rods painted black and white should be used; they are easier to see than plain rods.

Suppose the pegs are at 100-foot intervals. Bar the line at two consecutive pegs till the pegs are truly central; then put in a rod against the lower flange of the rail by each picket, as shown in *Fig.* 20. Take the third rod and place it in line with the other two at *a*, and bar the joint over at *a* (*Fig.* 21). The rod can then be moved to *bb*, and the joints barred to those points (*Fig.* 22). Finally the centres of the rails are barred into position by eye.

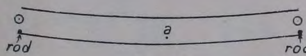


Fig. 20.

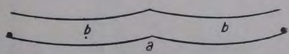


Fig. 21.

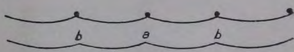


Fig. 22.

If the centre pegs are out of line you will have to use your rods in somewhat the same way, taking long shots back at the line behind you.

Curves, if trued up by a N.C.O. or Subordinate, must be done entirely by eye. All he can do is to remove chords and try and get a regular curve. If the Permanent Way Inspector knows the radii of the curves, he can get out, for the N.C.O. trueing the curves, a table of versed sines for various lengths of chords. To ensure rails taking a curve and not remaining a succession of chords, the joints are held in place at a and c (*Fig.* 23) by men with bars, while a third man places his bar on the other side of the rail at the centre b and bars it into the shape shown by the dotted line.

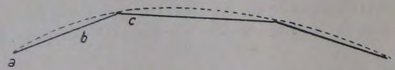


Fig. 23.

The jimcrow should be used sparingly; in fact it is not required at all for curves over 200 feet radius with the 24-foot 35-lb. rail. It must be used to straighten bent fish-plates.

When using the jimcrow (*Fig.* 24) a bar d is laid down near the rail and on it the jimcrow is rested; this keeps the screw out of the

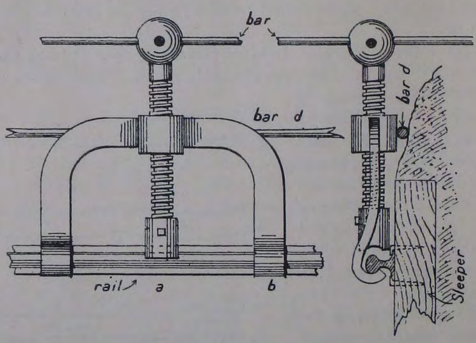


Fig. 24.

dirt and also enables the workmen to slide the jimcrow along the rail. If a rail is being bent the jimcrow is first put on with screw at a and the rail is bent as required; the workman then makes a mark (with his wet finger) at b; he then loosens the screw and slides the jimcrow till the screw is at b, and again bends the rail; continuing this process as far as is necessary.

To carry a jimcrow the men hang it by its claws to a bar on the shoulders of two men.

3 and 4. *Two Rear Sections.*—Behind all these are two Sections as already specified. All they do is to pick up bad joints, touch up straights and curves, and generally put anything right which has gone wrong.

The result should be a line good enough for 15 miles an hour and remaining so for about a week; after which regular maintenance gangs must be put on, at first at the rate of about 1 mate and 10 men to two miles.

Rate of Packing and Lifting.

If the formation was good and not very wavy, and if plenty of loose earth was available for packing, it was found easy to complete a mile of packing and lifting in eight hours. The average, however, was about 3 lengths per man of the six front Sections, or say 180 lengths in eight hours actual work.

Tools.

With regard to tools there is nothing to add to what is given in the *I.M.E.*, except that for loose earth packing nothing could be handier than the wooden beater we were given (*Fig.* 25).

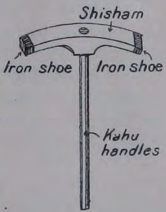


Fig. 25.

It was light and strong, made of shisham shod with iron, with a handle of kahu wood.

The iron shoeing, it is true, came off very soon, but that did not matter.

Cost of Platelaying.

The rate to be accepted for platelaying depends mainly on the speed at which material can be supplied. It is also slightly affected by the number of openings to be bridged. For instance, on the K.K.T. Railway our working party of about 240 men could do a mile pretty easily in the day if the material was there; yet our average only worked out to a little over half a mile, as hours were spent doing nothing, waiting for rails, etc.

Supply of Material.

It would appear from the graphic time-table (*Plate* I.) that there should be crossings about every 8 miles (on this particular line) and sidings about every 15 or 16. Then two trains could keep the platelaying going for 15 miles, and the remaining trains would keep filling up the last siding.

I believe that roughly there were available about 8 engines and rolling stock for about 2 miles of material; of the engines we may suppose one wanted for shunting, etc., in the main depôt, one sick and six available for material.

Each material train required two engines. From the time-table (allowing trains to run by day only) two trains can keep up a supply of a mile a day for 15 miles from the advanced siding.

Say we are doing 30 miles. We have only one train left to fill up the advanced siding from the base; that is to say we could only put $\frac{1}{2}$ a mile into the siding.

Thus, to work evenly, we should have to arrange for two trains one day and one train the next on each section; that is to say the platelaying gangs would get $\frac{1}{2}$ a mile of material one day and 1 mile the next, an average of $\frac{3}{4}$ mile during the last 15 miles. From this we must make a considerable deduction to allow for accidents, say 33 per cent., so an average of only $\frac{1}{2}$ a mile might be expected on the second section.

On the first section, making the same allowance for accidents, we might expect $\frac{2}{3}$ mile.

The average over both sections $=(\frac{2}{3}+\frac{1}{2})\div 2=\frac{7}{12}$ mile per diem.

Then every bridge causes delay and keeps a number of men idle. I should say roughly every 6 feet of opening takes an hour to cross.

Strength of Gangs.

Now the platelaying gangs employed must be strong enough to link the largest amount of material the trains can bring out, irrespective of their average performance; *i.e.*, though the average rate of supply is only $\frac{7}{12}$ mile, the gangs must be able to get a mile done in the day, for which they must be about 240 strong.

Rate of Laying.

As the material comes out at $\frac{7}{12}$ mile per day, 30 miles will be done in 52 days. Suppose there are 200 feet of openings to be bridged, this causes a delay of 33 hours or 4 days. The 30 miles will therefore take 240 men 56 working days.

Say the men are to earn As.9 per diem; then the rate must be :—

$$\frac{56\times 240\times \frac{9}{16}}{30}=\text{Rs.}252 \text{ per mile.*}$$

Adding Rs.20 per mile for loading up at the depôts we get a rate of Rs.272 per mile.

As a matter of fact on the K.K.T. Railway the men made As.9 per diem on a rate of Rs.250; but for the last 18 miles of the 30 the engines took $\frac{1}{2}$ a mile of material instead of $\frac{3}{8}$ of a mile.

* 1 rupee = 16 annas.

PART II.—PLATELAYING ON MILITARY LIGHT RAILWAYS.

To procure data relative to the rate of laying light lines for field service, advantage was taken of the presence of four companies of Sappers and Miners* near Kohat in the spring of 1902 to carry out certain experiments. It will be convenient to describe the whole in the same order as previously done with the 35lbs. rail.

FORMATION.

The formation of a light military line must of necessity be very rough ; cutting and filling will hardly be possible ; indeed it is most likely that the berm of an existing road will provide the necessary formation.

The berm of the road on which the Kohat experiments were carried out was utilised ; and on it was placed a layer of earth, about 5 feet wide by 5 inches deep, scraped from the road drains.

The grades were not severe except at the crossing of the Gumbat nalla, where there was a slope of $\frac{1}{20}$ on a curve of 100 feet radius.

The minimum curve allowed was of 100 feet radius and it was only required once, viz., in the Gumbat nalla. Curves.

Laying out Curves to suit Cut Rails.—It saves trouble if the curves are laid out to suit the cut rail. With a cut rail 3 inches shorter than the ordinary one, and a gauge of 2 feet 6 inches, it can be seen that with a curve of 120 feet radius all the inner rails are cut rails, with one of 240 feet radius every alternate one, and with one of 360 feet radius every third, and so on.

Thus if curves are laid out in multiples of 120 feet it is easy to arrange the supply and spreading of the cut rail frames (*Fig.* 26).

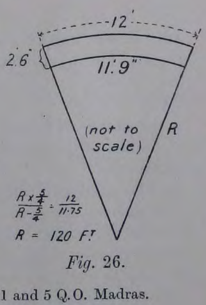


Fig. 26.

Instead of centre pegs, side pegs on a line clearing the sleeper by 6 inches were laid out.

* Nos. 5 and 6 Companies Bengal and Nos. 1 and 5 Q.O. Madras.

Centre pegs would not have been suitable as, with made-up frames, the log line would have been pinned down under the sleepers. Side pegs are less in the way and do not get knocked out so soon.

The pegs were laid out in straights and curves, and a rough traverse made for the use of the platelayer in linking.

Bridges.

Bridging would all be of the roughest field type, probably sleeper stacks or trestles, with rails used as girders; and ramps or diversions would be used whenever possible.

Permanent Way.

Rails.

The rail used was a 21-lb. flat-footed steel rail, 12 feet long.

These were made up into frames (carefully squared) with one steel sleeper keyed in the centre and one 12 inches from each end of the frame. The fish-plates and bolts were also attached to the frames (*Fig.* 27).

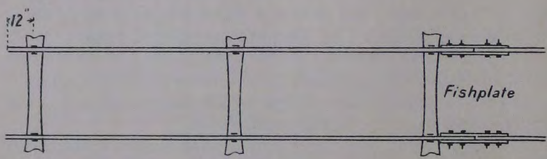


Fig. 27.

This frame weighs about 250 lbs. and was suited for animal draught. For light steam draught two more sleepers would be necessary, which would bring the weight of the frame up to about 300 lbs.

A percentage of frames are made up with cut rails; and these it is advisable to paint white all over, so that they may be immediately recognisable.

One hundred men can make up 1,600 frames in eight hours.

Sleepers.

The sleepers, keys, etc., were the same as shown in *Plate* XIX. of *I.M.E.* as Livesay's; they weighed about 25 lbs.

The fish-bolts were snapheaded with square shanks, and were very easy to work.

The fish-plates require no description. Untrained men are rather given to putting them on the wrong sides. The fish-plate is shaped to fit the rail (*Fig.* 28), and should be put on so, and not as in *Fig.* 29.

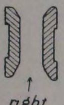


Fig. 28.

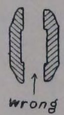


Fig. 29.

As described for the 35-lb. rail the bolts require oiling.

It is clear then that, before starting linking, the following arrangements must be made :—

1. Making up frames.
2. Oiling bolts.
3. Providing sufficiently strong parties to prepare the formation for at least a day's work ahead of the linking.
4. Arranging for a supply of sleepers for sleeper stacks, of timbers for trestles, and of rails suitable for use as girders.
5. Arranging for despatch of material by steam or animal traction as the case may be.
6. Provision of cut rails, points and crossings, diagram of curves, etc., of each day's work for the platelayer.
7. Removing two fish-bolts from the fish-plates which are on each frame, and storing in boxes for oiling as in (2).

Construction Trains.

The same considerations which affected steam traction in the discussion of the 35-lb. line are applicable on the lighter line, and it is therefore unnecessary to say more about them.

We know that two mules can draw a load of $\frac{1}{3}$ ton in an Army Transport cart weighing about the same (770 lbs.), or a total of $\frac{2}{3}$ ton, on good roads with gradients of $\frac{1}{25}$ at about $3\frac{1}{2}$ miles per hour. Mule Draught.

This gives a tractive force per mule (India) of about 50 lbs. A table of draught can now be constructed.

GRADE.	2 Mules, Tractive Force=100lbs.				Bagnall Engine, 4 Ton Axle Load, Tractive Force=4,800. R=10.†					
	Road R=60.*		Rail R=15.*		One Engine, Tractive Force=$\frac{2}{3}$ 4,800.†			Two Engines, Tractive Force=4,800.†		
	Load, Tons.	Cart, Tons.	Load, Tons.	Trolly, Tons.	Engine, Tons.	Load, Tons.	Trucks, Tons.	Engine, Tons.	Load, Tons.	Trucks, Tons.
0	$1\frac{1}{3}$	$\frac{1}{3}$	6	$\frac{1}{3}$	15	250	30	30	400	50
$\frac{1}{80}$	1	$\frac{1}{3}$	2	$\frac{1}{3}$	15	53	7	30	80	10
	4 Mules, Tractive Force=200lbs.									
$\frac{1}{50}$	$1\frac{2}{3}$	$\frac{1}{3}$	$3\frac{2}{3}$	$\frac{1}{3}$	—	—	—	—	—	—
$\frac{1}{40}$	$1\frac{1}{3}$	$\frac{1}{3}$	$2\frac{2}{3}$	$\frac{1}{3}$	15	29	4	30	38	5
$\frac{1}{30}$	1	$\frac{1}{3}$	$1\frac{9}{10}$	$\frac{1}{3}$	15	22	3	30	24	3
$\frac{1}{25}$	1	$\frac{1}{3}$	$1\frac{2}{3}$	$\frac{1}{3}$	—	—	—	—	—	—

* R=Resistance in lbs. per ton of load.
† See page 8.

This shows that :—

ON GRADE.	Number of Mules required to pull.			One Engine pulls.	Two Engines pull.
	$\frac{1}{3}$ Ton in A.T. Cart.	1 Ton in Cart.	2 Tons in Truck.		
0	2	2	2	30 tons load	40 tons load
$\frac{1}{80}$					
$\frac{1}{50}$		4	4		
$\frac{1}{40}$					
$\frac{1}{30}$				under 20 tons	20 tons load
$\frac{1}{25}$					

Thus we see that for mule draught it will be suitable to make up truck loads of two tons (16 frames). To these we can attach two or four mules as may be necessary. At special places, where heavy grades have to be encountered, relays will have to be provided.

It should be remembered that, although a very heavy load can be drawn on rails, nevertheless the exertion of starting—of overcoming the inertia of the load—is very great. Therefore all starting, halting or relay stations for full trucks should be on a slight down grade.

Assuming that it is possible to link 2 miles of this light material in 8 hours, we can make out a graphic time-table for the number of 2-ton trucks and pairs of mules (@ 1 pair per truck) required simply to spread the 2 miles in 8 hours (*Plate* II.). This supposes that there are other trains of animals in rear, which are just able to bring 2 miles of stuff to rail-head in time for the linkers to lay daily. The time-table shows that 23 trollies and 46 mules are required.

PLATELAYING.

Gauge 2 feet 6 inches ; rails 21 lbs., flatfooted, 12 feet long, keyed in pairs to three steel sleepers.

It would seem at first sight that linking up a lot of carefully prepared frames would be a very simple matter, simpler than ordinary linking. This however is not the case ; for, whenever there are any curves to be put in, the frames must be unkeyed and the rails slipped backwards or forwards to their correct position, and this is a very troublesome operation.

In ordinary linking there is no difference in the rate working on the straight or on a curve ; but with frames the rate on curves is less than half that on the straight.

The operations are :—

1. *Spreading* the frames on the formation.

2. *Skeleton Linking* up rapidly by inserting one fish-bolt. (The fish-plates are already loosely bolted to one rail by two fish-bolts).

3. *Full Linking ;* putting in the other bolt and tightening up all four.

4. *Rough Straightening.*—As for 35-lb. rail.

5. *Packing and Lifting.*—As for 35-lb. rail.

Detail of Parties.

Duty.	British N.C.O.	Native Officer.	Native N.C.O.	Sappers.
1. Log Line	—	—	2	—
2. Spreading	—	—	1	28 strong men.
3. Spacing Frames	—	—	1	—
4. Splaying Fish-plates	—	—	—	2
5. Placing Frames for insertion of 1st Bolt.	1	1	1	8, the most hard-working strong men available.
6. Bolt Distributors	—	—	—	4
7. Putting in 1st Bolts and Expansion Iron.	—	—	—	4, old weak men.
8. Loosening Keys and Squaring Sleepers.	—	1	1	6
9. Screwing up 1st Bolts	—	—	2	6
10. Second Bolters	—	—	2	20
11. Taking out and passing forward Expansion Irons	—	—	—	4
12. Trolly Men, unloading, pushing and cutting, etc.	—	1	2	50. These are the balance after all the other parties have been detailed.
13. Squaring Sleepers and Rough Straightening.	1	—	1	6

Tools.

The only tools actually required for the linking are :—

Log lines	2	
Pickets	24	
Hand hammers	15	
Drifts	10	For knocking out keys.
Wrenches	28	
Crowbars	4	
Cold chisel	1	
T squares	2	
Chalk	—	

1. *Log Line.*—The log line is laid out by the two N.C.O.'s along the side pegs, as already explained for the 35-lb. permanent way.

2 and 3. *Spreading and Spacing.*—Four men to a frame bring the frames from the trollies; and lay them down on the formation, as directed by the N.C.O. who spaces the frames.

4. *Splaying Fish-plates.*—To enable the linkers to slip the rails of each frame, as they link between the fish-plates of the last frame, it is necessary to loosen the bolts of the fish-plates and splay the latter outwards (*Fig.* 30).

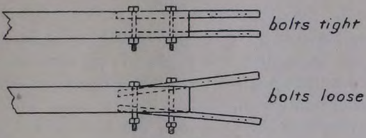


Fig. 30.

5. *Placing Frames on Straight.*—The British N.C.O. and Native Officer generally supervise, and decide when the linking is straight or curved and when to obtain curvature by omission of expansion iron.

The N.C.O. gives the word "link"; the men A (*Fig.* 31), whose duty it is to put in the fish-bolt, splay out the fish-plates with the heads of their hammers so that the fresh rails can be easily slipped in.

Fig. 31.

The first four of the men B "*placing frames*" stoop and, facing the N.C.O., seize their frame, call out "ready," and, on the word "go" from the leader, run the ends of the rails up against the other frame between the fish-plates.

6 and 7. *Putting in First Bolts, etc.*—The first bolters A, who have already received oiled bolts and nuts from the "*bolt distributors,*" close the fish-plates and put in the bolt, if necessary hammering it in with a hand hammer, and loosely screw on the nut.

The Expansion Iron is not yet in, because, if put in place before the frame is linked, there is often difficulty about getting in the bolt.

To put in the Expansion Iron the N.C.O. calls out "right"; on this word the four men B pivot the frame to the right (*Fig.* 32).

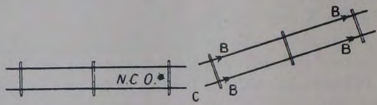


Fig. 32.

This causes a gap at *c*, by the fish-bolt slipping in the bolt-hole into which the expansion iron is placed; as soon as it is in the N.C.O. calls out "left," when the same is done to the left and the other expansion iron put in.

Finally the log line N.C.O. directs the four men B to move the frame right or left as the case may be until it is parallel to, and at the correct distance from, the log line.

Meanwhile the other four men D "*placing frames*" have got the next frame ready; as soon as the expansion irons are in, the N.C.O. calls out "link," and the same operations are repeated.

If however a curve has to be linked a different procedure is necessary (*Fig.* 33).

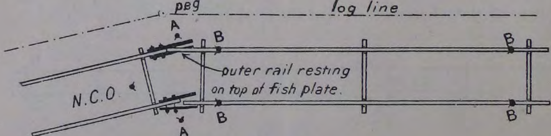


Fig. 33.

The N.C.O. gives the word "curve link," on which the four men B, as before, seize the frame and give the words "ready" and "go"; they do not however push both the rails of the new frame between the fish-plates of the last, but only the inner, and this one only is bolted; the other rail is raised if necessary, and laid on top of the rail or fish-plates of the last frame.

8. *Loosening Keys, etc.*—As soon as this has been done the men "*loosening keys*, etc.," with their drifts and hammers, loosen the three keys of the outer rail.

The two men B of the outer rail then slide this rail back through the lugs of the sleepers till it is clear of the fish-plates, and then slip it forwards again into its place between these same fish-plates; the bolt man then puts in the bolt.

As soon as this has been done the log line N.C.O. calls out "right" or "left," and the frame, with the sleepers still loose, is moved till it is parallel to the log line; the keys are then tightened.

I would here note that, during all the movements of the rails and frame while the keys are loose, the keymen must hold the sleepers up against the foot of the rail; otherwise they fall off, and the rail will only go in again if slipped right through the lugs of all three sleepers.

The frame being now keyed tight, the expansion irons can be put in and the frame finally brought parallel to the log line as in straight linking.

Finally the N.C.O. of the keymen corrects with a T square the sleepers of each frame after the linking has been completed.

9 to 13. *Completing.*—All other operations are the same as with the 35 lbs. line, and require no description.

Rate of Platelaying.

On the *straight*, spreading from heaps of 10 frames laid at proper intervals along the line, a mile was done in 2 hours and 11 minutes. Spreading from trollies it was done in 2 hours and 37 minutes.

On the *curve* a mile was done in 4 hours and 46 minutes.

Two and a half miles of mixed straight and curved work were linked at the rate of a mile in 3 hours 18 minutes.

I do not think much importance need be attached to these rapid rates, for material could never be supplied at these rates.

General Remarks on Military Light Railways.

The necessity for the use of light railways in India becomes more pressing every day.

As roads and railways improve and extend, and districts are opened up, the old methods of carrying goods by pack animals and in carts yield to railway transport.

The numbers of draught and pack animals available in our Indian frontier districts are becoming daily less and less; and some other means of carrying must be found to replace the hired carts, camels and mules of old days.

The military engineer must so treat his lines of communication that the load which can be hauled thereon may be a maximum.

Whenever possible steam and a medium line would be used, followed by steam on a light line, the latter changing, whenever engines could not run, to a light line for animal draught, the communication ending in an ordinary cart road or pack track. The ruling factors are time and the character of the ground to be crossed.

Rate of Laying.

It may be taken as an axiom that every Field Light Railway must be laid with the haulage and rolling stock which will be available to work it with, and that it will be laid telescopically from a Base Depôt.

We have seen that, as far as the actual linking goes, between 8 and 4 miles a day might be laid by working through the 24 hours. The circumstances under which the material could be brought up at this rate over any distance are impossible to imagine. A supply of 2 miles a day of light material on a difficult road up to a distance of 30 miles would be good. This however a railway engineer can work out; given the line, he can decide its capacity, what rolling stock is required and at what rate that rolling stock could lay it.

As an *outside* estimate, then, the rate at which a light line could be laid for any distance may be set down as 3 miles a day.

Formation.

A Field Railway may be laid :—

(*a*). On a new formation level off existing roads.
(*b*). On the side of an existing cart road.
(*c*). Partly on both.

(*a*). Is not likely to be possible, as the time of preparing the formation level would probably be prohibitive.

(*b*). Is the more likely state of affairs for the bulk of the length of the line.

(*c*). Is the almost certain location. The line would mainly run on the edge of the road, but would be diverted therefrom to avoid blocking ordinary cart traffic at bridges, cuttings and banks and wherever the ground alongside was favourable. The formation must be such that it can be prepared as quickly (3 miles per diem) as the rails can be brought up and laid.

Grades.

As a rough guide it would appear that, with engines of two 4-ton axles, it would be possible to run a light 2′ 6″ line over ground where there might be constantly recurring gradients up to $\frac{1}{40}$.

With engines of four 4-ton axles, gradients of $\frac{1}{30}$ could be passed. Of course curves and short wheelbases must not be lost sight of.

If steeper grades are to be encountered, animals must be used to draw the trucks. If slopes of more than $\frac{1}{20}$ be often met, trucks must give way to carts or pack.

For steam, nothing less than 21 lbs. appears suitable ; for animals, 14 lbs. would probably suffice. Rails.

PART III.—BLASTING, EXCAVATION AND DETERMINATION OF RATES.

The following notes, relative to excavation on the formation level of the Khushalgarh-Kohat-Thal Railway, are the experience of a year's work.

BLASTING.

The rock was sandstone, varying from very soft surface layers to very hard blue rock in the lower strata.

Charge.

After many experiments it was found that 3 oz. English, or 4 oz. country, powder per foot depth of bore-hole was the best charge; between 2 feet and 3 feet—subject to lie of strata—the best depth; and between 1 foot and 4 feet the most suitable distance back from the face, according as the rock was hard or soft and according as it had longitudinal faults or not.

In rock of average hardness dynamite is no more effective than powder, and its price (about Rs.2 per lb.) is prohibitive with cheap labour.

English powder costs from As.8 to As.6 per lb., and is very effective.

Country powder in soft and medium rock is nearly as effective as English powder, if the charge be increased by $\frac{1}{3}$; and it only costs As.2/7 per lb.

The main point with country powder is to tamp it well; also to see that it is dry, to ensure which it should be exposed to the sun.

Loading and Tamping.

Some tamping clay must first be got ready and well pugged, but not too wet.

To load the hole :—

(1). Dust a little dry sand or dust into the hole, to make sure it is dry.

(2). Put in half the charge.

(3). ,, the fuze.

(4). ,, other half of charge, and tap with tamping rod till top of charge is flat.

(5). Pour in about half an inch in depth of dry sand or dust and tap it with tamping rod.

(6). Tamp with clay, using a short wooden bar and a sledge hammer.

Lighting Fuzes.

Split open the end of the fuze longitudinally with a knife and open with thumb-nail as in *Fig.* 34. The powder is then exposed and can be lighted with a pointed fire-brand or piece of charcoal.

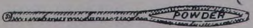


Fig. 34.

No man should light more than six fuzes, and no fuze should be shorter than 2 feet.

Effect of Powder.

In soft rock country powder got out 60 cubic feet to the lb. In hard rock in wide cuttings the out-turn was sometimes as low as 20 cubic feet. In confined places, small drains, etc., the result sometimes would be as low as 5 cubic feet per lb.

EXCAVATION.

One man can excavate with pick and shovel :—Of soft loamy soil, 450 cubic feet ; of other soil, according to hardness 450 to 100 cubic feet.

In pick and jumper work he can excavate of hard soil and soft rock 100 to 40 cubic feet.

One man can bore :—Of sandstone, 7 feet ; of granite, 1 to 2 feet, using about a pint of water per foot.

Loading.

One man can load into barrows } 340 cubic feet of excavated spoil.
,, ,, ,, ,, on to donkeys }
,, ,, ,, ,, into trucks, 4 feet high, 200 cubic feet.
,, ,, ,, ,, into baskets 340 cubic feet.

Emptying.

One man can empty from trucks 300 cubic feet.

No time allowance is required for barrows, baskets or donkeys, as emptying therefrom is practically instantaneous.

Carrying.

A man can walk 12 miles a day wheeling a barrow or carrying a basket ; donkeys go the same distance.

To push a truck (60 cubic feet) on the level, 3 to 4 men are required ; up a slope of 1 in 80, 9 men are required ; say an average of 6 men.

Care should be taken to maintain separate tracks for outgoing full trucks and returning empties.

N.B.—These measurements are solid and do not take account of increase due to excavation.

Barrow men cannot work at a steeper slope than 1 in 8, nor basket men and donkeys at a steeper slope than 1 in 4.

Ramps.

To make up for extra labour in surmounting ramps, add 3 yards for every foot rise for barrows, and one yard for baskets and donkeys.

Contents. Barrows carry about 1 cubic foot of unexcavated spoil.

Donkeys ,, do.

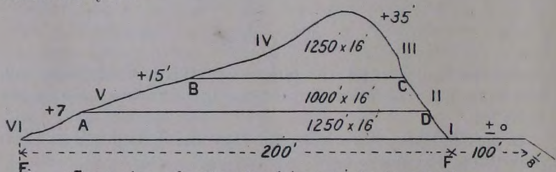
Baskets ,, $\frac{1}{4}$ to $\frac{1}{3}$ cubic foot.

Trucks (60 cubic feet) carry 40 to 45 cubic feet.

Breaking Up. One man can get out with jumpers, and break up, 50 cubic feet of rock that has been blasted with powder.

EXAMPLES OF ESTIMATING LABOUR, POWDER, ETC., ON CUTTINGS.

Excavation from Cuttings. Say you have six Sections of 10 men each to employ on the cutting shown in *Fig.* 35.



Examples of estimating labour, powder, etc. on Cuttings.

Fig. 35.

First divide the cutting up into tasks, so that all will be finished about the same time.

The divisions shown in *Fig.* 35 will do; the top is softer than the rest, but has to be lifted; the bottom piece is harder, but can be taken out at ends without lift; the centre piece is the smallest, for it has to be lifted a long way.

At first, as shown in plan, *Fig.* 36, the parties begin carrying out with barrows.

After a while VI. will have got past A,

V. ,, ,, B,

I. ,, ,, D,

II. ,, ,, C,

and the barrows will no longer be able to run except at E and F.

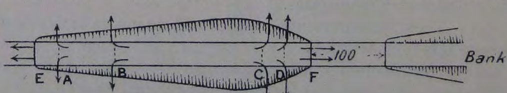


Fig. 36.

Thus the spoil of the upper four sections must be taken out in baskets, as ramps for barrows cannot usually be arranged in a rock cutting (*Fig.* 37).

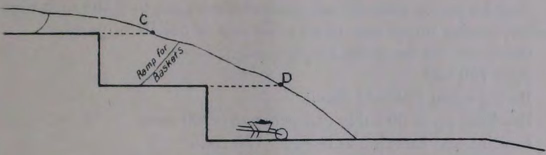


Fig. 37.

Data :—Mean width = 16 feet. 1 lb. powder gets 30 cubic feet rock. Spoil to be placed twice depth of cutting + 20 feet away from edge of cutting, except at F, where No. I. Section is to run into a bank 100 feet away.

First take III. and IV. Sections.—The task of *each* of these is 10,000 cubic feet.

The average lift will be $\frac{1}{2}$ average depth = 5 feet = ramp of 20 feet at $\frac{1}{4}$. To this we add 5 yards for extra labour in rising 5 feet; therefore lead to edge of cutting $= 20 + (5 \times 3) = 35$ feet.

The average distance of spoil from bank will be average of twice depth of cutting + 20 feet $= 2 \times \frac{35}{2} + 20 = 55$ feet; therefore total mean distance spoil has to be carried is 90 feet.

But this is only the inner edge of the spoil bank, which will probably be 20 feet or more wide. We may take average distance of centre of spoil as 110 feet.

Powder (country) required $= \frac{10000}{30} = 333$ lbs., @ Rs.13 per maund.*

Fuze, say 1,500 feet $= \frac{15}{72}$ of cask, @ Rs.60.

†Boring @ 4 oz. to foot $= 333 \times 4 = 1{,}332$ feet = 190 men.

‡Breaking up @ 50 cubic feet (pick and jumper) $= \frac{10000}{50} = 200$ men.

§Loading into baskets $= \frac{10000}{340} = 30$ men.

‡Carrying $4 \times 10{,}000$ baskets for 110 feet and back @ 12 miles a day $= \dfrac{220 \times 40{,}000}{5{,}280 \times 12} = 140$ men.

* 1 Maund = 80 lbs.
† See page 214.
‡ See page 216.
§ See page 215.

This gives a total of 560 men. Allowing As.6 per man, and adding the cost of powder and fuze and 10 per cent. for profit and repairs, the rate per 1,000 cubic feet = about Rs.29. The tasks would take 56 days work to finish.

Now let us see what the above would work out to if the rock were softer, coming out at rate of 60 cubic feet to one lb. of powder.

Powder = 166 lbs. @ Rs.13 per maund.

Fuze 750 feet.

Boring = 666 feet = 95 men.

Breaking up @ 50 cubic feet per man = 200 men.

Loading and carrying as before = 170 men.

A total of 465 men and a rate of about Rs.22. Time required 46 days.

The work of No. II. and V. Sections would be estimated in the same way.

Let us now work out that of Nos I. and VI. who will be barrowing and trucking.

No. VI. Section is to barrow out to a place the edge of which must not be less than 20 feet from edge of cutting.

Barrows cannot work at a steeper slope than $\frac{1}{8}$, probably the men will choose $\frac{1}{10}$. The heap will then be a circular wedge (*Fig.* 38).

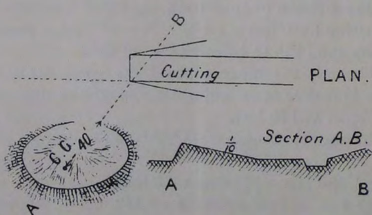


Fig. 38.

The mean lead will be distance between centre of gravity of heap and centre of gravity of portion of cutting excavated, which on working out will be found to be about 100 feet.

Powder @ 30 cubic feet per lb. $= \frac{10000}{30} = 333$ lbs., @ Rs.13 per maund.

Fuze $= 1{,}500$ feet $= \frac{15}{72}$ of a cask @ Rs.60.

Boring @ 4oz. powder per foot = 1,332 feet	= 190 men	Total 462.
Breaking up @ 50 cubic feet	= 200 ,,	
Loading into barrows @ 340 cubic feet ...	= 30 ,,	
Carrying 100 feet + 4 × 3 × 3 feet (for rise of 4 feet)	= 42 ,,	

Labour @ As.6 per man	= Rs.173.0
Powder	= ,, 54.0
Fuze	= ,, 12.8
	239.8
Add 10 per cent. for contractor and repairs, etc.	24.0
Total cost	Rs.264.0

or a rate of Rs.26.6 per 1,000 cubic feet.

The ten men would finish in 46 days and remove about 22 cubic feet per day each.

For No. I. Section the average distance spoil has to go will be distance between centres of gravity of cutting and bank (*Fig.* 39).

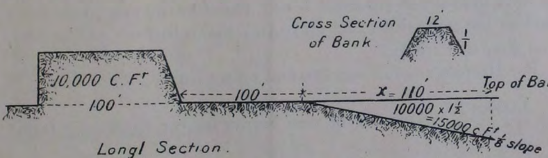


Fig. 39.

Remember that excavated stuff increases in bulk, say 50 per cent. Assuming $x =$ length of bank filled, then.

cubic content

$$= 10{,}000 \times 1\tfrac{1}{2} = 15{,}000 = \tfrac{1}{2}\,x \times \frac{x}{8} \times 12 + 2\left(\tfrac{1}{3}\,x \times \tfrac{1}{2}\cdot\frac{x}{8} \times \frac{x}{8}\right)$$

$$= \left(\frac{x}{2} \times \frac{x}{8}\right)12 + \left(\frac{x}{2} \times \frac{x}{8}\right)\frac{x}{3}\cdot\tfrac{1}{4} = \frac{x}{2} \times \frac{x}{8}\left(12 \times \frac{x}{12}\right)$$

from which $x = 108$ feet nearly, say 110.

Then distance between centres of gravity $= \frac{100}{2} + 100 + \frac{2}{3}.\ 110$
$= 225$ feet.

Filling 10,000 cubic feet into trucks $= \frac{10000}{200} = 50$ men.

Pushing $\frac{10000}{40} = 250$ truck loads 225 feet and back at 6 men per truck and 12 miles a day = 10 men roughly.

Unloading trucks $= \frac{10000}{300} = 33$ men.

Men for boring and breaking up, and powder and fuze, as in previous instances.

Thus for hard rock we have 483 men and a rate of about Rs.27 per 1,000 cubic feet; for softer rock about 390 men and a rate of Rs.20.

Distribution of Labour.

It is perhaps hardly necessary to state that one can only put a certain number of men to work in a certain space, and that it does not at all follow in any given case that (say) 100 men would finish the work much quicker than 10.

In a cutting 15 feet wide you cannot economically work more than about 12 men in one heading; and you cannot work more than 5 barrows or 1 truck at a time.

Labour on, and cost of, banks can be estimated on the same principles.

Lead from Cuttings.

To compile rates for lead. Up to 200 feet barrows work more cheaply than trucks (40 cubic feet); therefore we may make out a rate on the supposition that up to two chains barrows will be used, and after that trucks.

For 100-foot run full and 100-foot return empty,

$$\frac{1{,}000 \times 200}{12 \times 5{,}280} = \text{number of men barrowing per 1,000 cubic feet;*}$$

at As.6 per man this = Rs.1.3 per 1,000 cubic feet.

$$\frac{\frac{1000}{40} \times 200 \times 6}{12 \times 5{,}280} \text{ (men pushing)} = \text{number of men trucking,*}$$

which at the same wage = As.3 per 1,000 cubic feet.

Therefore for lead the schedule would contain the following statement:—

Lead for the first chain (Rs.1.3 per 1,000) is included in the initial rates. Lead for the second chain will be paid for at the rate of Rs.1.3 per 1,000, and for every succeeding chain at the rate of As.3 per 1,000.

* See page 216.

Lift is all done by basketing. For the first 5 feet the fillers lift the spoil into baskets on the edge at the rate of 340 cubic feet per man, and the baskets are carried away 50 feet (*Fig.* 40). Lift.

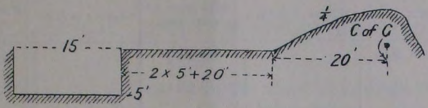


Fig. 40.

At As.6 per man this costs $\dfrac{100 \times 4\ (1{,}000)^{*}}{12 \times 5{,}280} \times \frac{6}{16} = \text{Rs.}2.6$ per 1,000 cubic feet.

But we have already allowed Rs.1.3 in the rate for lead of first chain, therefore add for 5 feet lift Rs.1.3.

For the next 5 feet down to 10 feet depth (*Fig.* 41)

$$\text{cost} = \frac{2\{20 + (5 \times 3) + 40 + 28 + (3 \times 3)\} \times 4{,}000}{12 \times 5{,}280} \times \tfrac{6}{16} = \text{Rs.}5.\ 10 \quad \text{per}$$

1,000 cubic feet, or an increase of Rs.3.4 on first 5 feet.

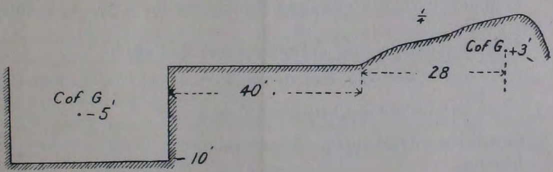


Fig. 41.

The next and every succeeding 5 feet will be found to require an addition of about Rs.2.

Therefore :—

For cuttings from	0 to 5	feet deep, add Rs.	1.3	per 1,000 cubic feet.
,,	0 to 10	,,	4.7	,,
,,	0 to 15	,,	6.7	,,
,,	0 to 20	,,	8.7	,,
,,	0 to 25	,,	10.7	,,
,,	0 to 30	,,	12.7	,,
,,	0 to 35	,,	14.7	,,

* See page 216.

Rates.

We are now in a position to schedule our rates for rock cuttings (*Plate* III.).

(1). *Excavation.*

Depth.	Nature of Rock.	Rate per 1,000 cubic feet.	Nature of Rock.	Rate per 1,000 cubic feet.
From 0 to 5 ft.	Soft rock coming out at 60 cubic feet per lb. of country powder.	Rs.20.9	Hard rock coming out at 20 cubic feet per lb. of country powder.	Rs.36.3.
,, 0 to 10 ,,		,, 23.13		,, 39.7.
,, 0 to 25 ,,		,, 25.13		,, 41.7.
,, 0 to 20 ,,		,, 27.13		,, 43.7.
,, 0 to 25 ,,		,, 29.13		,, 45.7.
,, 0 to 30 ,,		,, 31.13		,, 47.7.
,, 0 to 35 ,,		,, 33.13		,, 49.7.

(2). *Lead.*—For first chain of 100 feet, Rs.1.3 is included in above; for second chain add Rs.1.3; for each succeeding chain As.3.

(3). *Lift.*—No lead for spoil lifted, unless carried by order beyond twice depth + 20 feet.

Rough Rate for Dynamite and Granite.

In granite dynamite gets about 8 cubic feet for 3 oz., *i.e.*, 40 cubic feet per lb.

Assume dynamite, fuze and caps to cost Rs.2 per lb.

1,000 cubic feet = 25 lbs. dynamite. At $1\frac{1}{2}$ oz. to foot this $= \frac{16}{1\frac{1}{2}} \times 25 = 260$ feet boring = 130 men.

Clearing and breaking up = 20 men.
Loading = 3 ,,

Then total cost comes to :—

	Rs.	As.
Dynamite, etc.	50	
Labour, 153 men at As.6	57	
Lead	1	3
Contractor's profit, etc., 10 per cent.	11	

Under 5 feet deep ...	Rs.119	0	per 1,000 cubic feet.
From 0 to 5 feet deep	120	3	,, ,,
,, 0 to 10 ,, ,, ...	123	7	,, ,,
,, 0 to 15 ,, ,, ...	125	7	,, ,,
,, 0 to 20 ,, ,, ...	127	7	,, ,,
,, 0 to 25 ,, ,, ...	129	7	,, ,,

PART IV.—SAFEGUARDING OF RIFLES BY TROOPS IN CAMP.

During the cold weather in India the rifle thief puts in most of his work. I imagine the main reasons for his abstaining during the hot months from pursuing his avocations are :—first that the trans-border people move higher up the hills during the heat and therefore are further away from the scene of action, and secondly that during the hot weather nights people are much more wakeful—mainly owing to being forced to sleep in the day—and hard to surprise ; also the night is some four hours longer in mid-winter than it is at mid-summer.

The thief's favourite time is a cloudy, windy night, when rain is falling and tempting the sentries to snuggle down into the collars of their coats ; and he always arranges his expeditions for the moonless half of the month. Therefore, unless you are encamped actually on the border, where the thieves can take instant advantage of favourable climatic conditions, you need only expect a visit on those nights during the months of October, November, December, January, February, March and April on which there will be no moon between the hours of 10 p.m. and 6 a.m.

The camp must be surrounded by some obstruction which cannot be crossed at all, or cannot be crossed without making a noise, being seen or leaving signs of having crossed.

We found the easiest protection to put up was as shown in *Figs.* 42, 43 and 44. This is almost impossible to cross without noise and quite impossible to cross without displacing all the top stones and most of the parapet ; even dogs cannot cross without doing so.

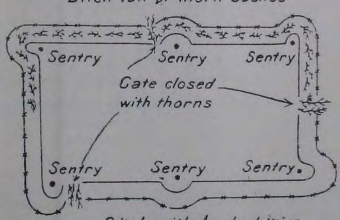


Fig. 42.

The sentries with loaded Sniders or, when there are not enough of these, the guns of the officers, occupy suitable positions, and by them sleep their two reliefs.

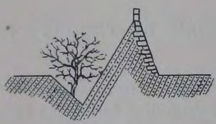


Fig. 43.

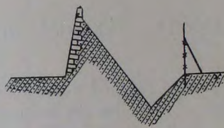


Fig. 44.

To ensure that any signs of the wall having been crossed may be at once found out a patrol (1 Sapper) with a lantern is kept constantly patrolling each half of the camp perimeter.

The following points with regard to safeguarding rifles have to be borne in mind :—

(1). A man should never lay a rifle down on the ground ; a rifle must always be (*a*) in the man's hands or (*b*) slung over his shoulder or (*c*) locked up in the rack.

(2). Parties of less than six should never be allowed with rifles outside the camp.

(3). Lee-Metford rifles should never be used by sentries, as this will only lead to their murder for the sake of the rifles.

In standing camp the simplest plan for securing rifles is to pass either a chain or a long bolt, with a padlock at one end, through the trigger guards and through an eye anchored to the ground (*Fig.* 45).

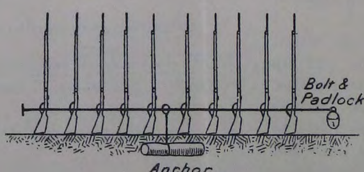


Fig. 45.

The whole of the rifles can be kept thus in the centre of an E.P. tent ; and each night one Section (along with the guard) sleeps round the arms, one man being sentry over them through the night.

In camp on the march arms must either be attached by the sling to the wrist, or chained to the tent pole or to a man. But none of these methods are safe unless, to each separate lot of rifles (say the rifles of every two Sections), there is a man awake on watch throughout the hours of darkness.

The following are some instances of thefts :—

1. Theft succeeding through sentry being armed with a desirable rifle (L.M.) and not protected by any obstacle or a light.

At Munda (Chitral Expedition) a sentry of the K.O. Scottish Borderers with a L.M. rifle was stalked by a Pathan. The latter crept close in the dark and threw pebbles over the sentry's head. The sentry turned his back on the unseen enemy and strained his eyes to see what was causing the noise made by the falling stones ; whereon the Pathan was on to him, I think killed him, and went off with the rifle.

2. Theft succeeding owing to rifle not being attached to the wrist by the sling (some regiments use dog chains) when on sentry-go.

The verandah of the guard-room of the 35th Sikhs at Peshawar, on the front towards the Circular Road, is supported on pillars. There were two sentries, whose beat was from the centre outwards to each end of the verandah.

In front of the guard-room were lamps, throwing a light on the ground near the verandah, somewhat as shown in *Fig.* 46.

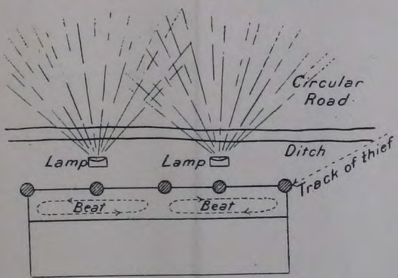


Fig. 46.

The thief managed to crawl up to one of the end pillars unseen ; when the sentry arrived there the former shot him in the stomach with a pistol and got away with the rifle (a M.H.).

3. Theft succeeding owing to absence of precaution of having a watch awake over arms.

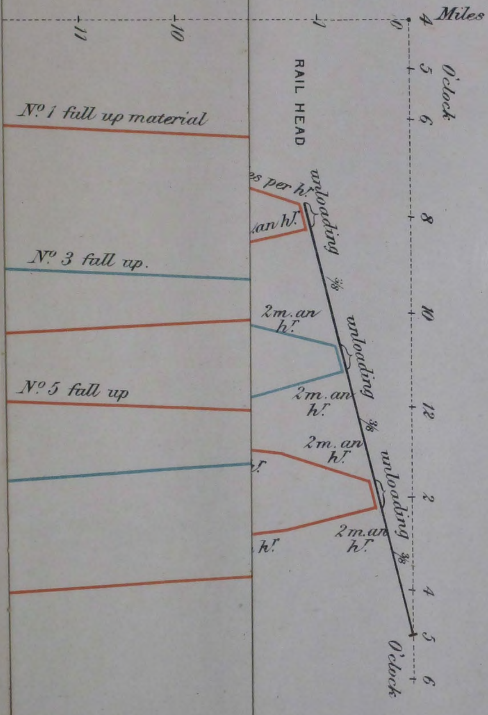
Thieves got in among some Martini-Henry rifles in Kohat, which were bolted down as shown in *Fig.* 45. Being unobserved they unscrewed the trigger guards.

The above instances will serve to show what slippery persons these professional rifle-stealers are.

There are of course other methods of balking them, besides those I have given, such as burying your rifles and sleeping on top and lighting up the perimeter with lamps.

GRAPHIC T

PLATE I.



PAPER VII.

THE CHILE-ARGENTINE BOUNDARY COMMISSION, 1902–1903.

BY

COLONEL SIR T. H. HOLDICH, C.B., K.C.M.G., K.C.I.E.,
LATE R.E.

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HISTORY OF DISPUTE.

THE Chile-Argentine boundary dispute in Patagonia was based (as such disputes usually are) on geographical misconceptions. So long as Patagonia was held by races of Indians, who scoured its wide pampas and raided their borders in heroic but futile protest against the advance of civilization, no great interest was ever aroused by rival claims for its future possession; but when the Indians were gradually driven back and out-manœuvred by the slow process of a destructive guerilla war in which the present President of the Argentine Republic, General Roca, bore a distinguished part, the discussion as to the right and title to the land immediately became acute.

On the eastern side of the Southern Andes, stretching from the Atlantic to the mountains, was the rapidly rising and progressive republic of Argentina. West of the Andes, occupying a long narrow stretch of maritime country and holding command of the Pacific, was Chile. The history and traditions of both countries were equally derived from Spain; but the great wall of the Andes had separated the peoples, and the natural effects of environment had tended towards the development of two distinct nationalities.

If you look at a map of South America you will see the mountain system of the Andes extending through the whole length of the continent. It comprises a long series of majestic mountain ranges and vast altitudes, which, for the most part, are as effectual a barrier between east and west as nature could devise. Throughout the system, where it parts Argentina from Chile *north* of the parallel of 41° S. latitude, there occurs a central meridional range, which is the great continental water-parting, or divide, from which the drainage flows to the Atlantic on the east and to the Pacific on the west. The two geographical principles of a high continuous mountain range and a dominant or continental water-parting are here combined. It is perhaps an unusual feature in the world's geography that these two governing principles of orographic structure should coincide through so great a space. Nothing could serve the purpose of a well-defined, indestructible and, for the most part, impassable international barrier than the main range of the Cordillera which forms these northern Andes.

It was not surprising therefore that, when the Treaties were framed which dealt with the more *southern* or Patagonian section of the Andes, a similar coincidence of these two principles should be assumed. Maps (*i.e.*, accurate topographical maps) of the complicated region of the southern Andes did not exist; the Indians were still in possession, and exploration was impossible. Treaties (and protocols subsequently added to the treaties) were perforce based on conjectural geography; but, with wise foresight, they provided for arbitration under certain contingencies by means of experts from either side.

Points in Dispute.

The boundary was, in general terms, to follow the crest of the main range of the Cordillera which parted the waters. When it was found that there was no continuous main range which was also the main water-parting, and that most of the great rivers of southern Patagonia had their sources amongst the moraines and foothills that bordered the eastern Pampas, and then followed a highly eccentric course transverse to the Andine Cordillera to the Pacific, each side claimed that the boundary should be determined by that geographical condition which was most favourable to its own interests. Argentina claimed that the massive band of western mountains, snow capped and glacier streaked, which overlooked the

Pacific was, in spite of the wide transverse depressions which let the rivers through, the main range of the treaty. Chile claimed the true continental divide, the central water-parting to the east of the Andes, although that water-parting was often represented by wide flat spaces of marsh-covered land of no great altitude, and might (so far as the treaty makers knew) have been interrupted or destroyed altogether by a central lake depression with no hydrographic outlet whatever—such as occurs in other lake regions of the world.

Appointment of Arbitrators.

Experts were accordingly appointed, but they failed to come to a mutual understanding; and at last, when war seemed inevitable, the final appeal to British arbitration was mutually accepted. But, without a geographical knowledge of the country concerned, British experts could not, any more than Argentine or Chilian, decide between the conflicting evidence which was so ably marshalled to the assistance of the arguments which supported the rival pretensions of the two contending nations. Maps were a necessity, and maps took time to prepare; and two or three years elapsed before even the geographical outlines of the disputed territory were defined.

Appointment of British Commissioner.

Meanwhile another political crisis supervened; and it was found advisable to send out a British Commissioner with instructions to examine the territory in dispute in the Patagonian Andes with a view to furnishing such geographical evidence as was necessary in order to frame an award.

Examination of Country.

Accordingly, early in 1902 (almost too late for the Patagonian summer) a party which I had the honour to lead—comprising Capts. C. L. Robertson and W. M. Thompson, of the Royal Engineers, Capt. B. Dickson, of the Royal Artillery, and Lieut. H. A. Holdich, of the Indian Army—started for an exploratory expedition which was full of indefinite responsibility.

It had to be carried through about 1,000 miles of mountainous country without roads, or bridges, or supplies, and to include the examination of many hundreds of miles of the Pacific coast at a time when equinoctial gales might be expected; whilst the whole programme was to be condensed into the few remaining months of the short Patagonian summer before winter snows blocked the way to the coast. It could of course only be done by dividing the party.

In Capt. Robertson I knew that I had an able assistant who had more than once before helped me in the tight places of the Indian Frontier, and Capt. Dickson had shown that he knew what rough exploring meant in Africa. Consequently I confided to Capt. Robertson's care all the southern section, the most rugged and difficult of the Southern Andes; and detailed Capt. Thompson to help him. Capt. Dickson took charge of certain outlying areas to the north, which demanded special attention. I myself took the coast examination, which included the Pacific harbours and roads therefrom into the interior (a critical point in the political position) and the northern section of the mountain area.

Thus Robertson started south direct to the Magellanes territory and the Ultima Esperanza country, with instructions to work northward till he met me. Meanwhile I went first to Buenos Aires; then crossed to Santiago and Valparaiso; thence worked southwards (in a Chilian cruiser placed at my disposal by the Chilian Admiralty) through the Messier Straits to the same point of dispute at the head of the Ultima Esperanza (or Last Hope) inlet, from which Robertson was to take off; from there I passed northwards again through the Pacific archipelago, working with Chilian ships to the river mouths and the embryo ports leading to those jungle-cleared roads which it was necessary to examine; and finally, crossing the Andes again by the Perez Rosalez Pass to Lake Nahuel Huapi, I worked slowly southwards through the great mountains till I effected a junction with Robertson about the eastern margin of Lake Buenos Aires.

I left Valparaiso early in March. By the end of May I was at Lake Buenos Aires, and the snow was then thick around us. Daily hurricanes from the west and north-west swept through the mountains and across the pampas, driving us before them to the Atlantic coast. It was not without some risk and difficulty that the whole Commission party cleared out from Patagonia. But we had seen the whole country. We had tested the mapping; and we at least knew enough of the conformation of the country to be able to furnish such geographical evidence as was required for the framing of an award.

We owed our success, firstly to the personal influence and the good understanding which was maintained by the two Presidents of the Republics, President Roca of Argentina, and President Riesco of Chile, whose sympathies were altogether in favour of a peaceful and rapid conclusion to our enterprise; and secondly to the excellent arrangements which were made for transport and supplies, which, it must be remembered, were extended over districts previously unsurveyed, only partially known, and covering an enormous area. In this connection I cannot but remember my old friend and adviser Dr. Francesco Moreno who, more than any man, has made Patagonia his study and whose reputation as a scientist is world-wide. He possesses the genius of organization. Such was the general progress and conclusion of the first part of the Chile-Argentine boundary programme.

Demarcation of Boundary.

The second part was the direct result of the award given by H.M. King Edward VII. in November, 1903, which entailed the demarcation of the now defined boundary.

The open summer season of Patagonia lasts but a few months at most; and about 900 miles of boundary, in an inconceivably rough and difficult country, had to be demarcated by the erection of pillars at critical points within that time. The party was the same as before, with the addition of Capt. H. L. Crosthwait, R.E., who, like Capt. Robertson, brought Indian experience to the field of action.

As regards the surveys there is one point to which I would particularly draw attention. Without maps of some sort it would have been absolutely impossible to define an award; without maps carefully verified and revised it would have been impossible to locate a single boundary mark. It is nonsense to talk of defining a boundary in treaty agreements before maps exist; the only question of importance is how much—and what sort of—mapping is required.

In a wild and desolate region, such as the Southern Andes, so long as the definition of the boundary is based on natural or geographical features, it may not be necessary to have very perfect topographical illustration of those features. A main water-parting, so long as it can be ascertained that such a feature is continuous, requires little artificial aid to render it recognizable. Similarly with a main range, if the crest of it is to define the boundary; many of the great international boundaries of the world are the summits of snow-bound mountain ridges of vast altitude, where no one will ever dispute the right of way.

If the 900 miles of Andine boundary which we had to demarcate had been left in the snows and glaciers of a central Sierra of the Cordillera, very little artificial demarcation by pillars would have been necessary, and very general geographical mapping would have served our purpose. The demarcation was not, however, quite so simple.

It is true that many long stretches of the boundary were indicated by the lofty crest of continuous mountain chains or ridges. But there were other long stretches, some of which passed through the open plains of the eastern moraine formations of the Andes, where the great continental divide was exceedingly hard to recognize; and sometimes the boundary dipped down to the transverse lakes and rivers intersecting the mountains, or crossed a space of open grass land where grazing rights had to be recognized and accounted for. There the boundary pillars came into play; these were light angle-iron lattice-work constructions, about 16 feet high, and were conveyed to their appointed places, which were already marked, and arranged by the aid of topographical maps of sufficient accuracy to enable the members of the tribunal to say positively and beyond the chance of dispute where the pillars should stand.

In the making of these maps both Governments had been concerned. They were constructed by the universal method of plane tabling based on triangulation. The surveyors were engineers and topographers drawn partly from Argentine and Chilian sources, and partly from the topographical schools of Italy, France, Switzerland and Germany—men who knew their work thoroughly and were experts with the plane table. All we had to do with these surveys was to examine and check the results.

The triangulation was irregular, and the results of the series which were carried out on different systems by the Argentine and Chilian surveyors respectively were by no means in perfect accordance. There appeared to be a certain error introduced by the initial data in the first place, and by the want of a uniform system in the second. Subsequent revision and comparison (for no comparisons whatever had been made before our advent) greatly reduced those discrepancies; and, the differential results being fairly satisfactory in spite of absolute disagreement here and there, no such effect was produced on the topography as would invalidate the mapping for the purposes of boundary demarcation.

The difficulties of surveying in that country were peculiar. A country of mountains with wide plains interspersed may (in spite of forest growth) be a very easy country to survey, and may be reduced with very great rapidity to fairly accurate geographical mapping. It was not so in this case; but I will not describe in detail the special difficulties which beset the Andine surveyors. Perhaps the greatest was the prevalence and the terrific violence of westerly gales of wind; it was seldom possible to set up an instrument on the summit or highest point of any hill, and all experienced surveyors know the results of triangulation effected from stations which are indistinguish able at a distance.

The method of demarcation was simple. Remember that in this, as in so many other boundary demarcations which have occurred lately, time was the essential, the governing, principle. The unsettled conditions resulting from an unsettled boundary meant the loss to the countries concerned of a vast amount—expressed financially—and it might even have meant war. Many millions had been spent on preparations for war, millions more hung in the balance till it was known for certain that the question was finally and irrevocably settled. We had, in short, to pillar up the boundary within the limits of a few months.

It was done by attacking it not only at its two ends, but all along the line at once. Each assistant was told off to a certain section, within which he was guided by his maps to the absolute position of each pillar to be erected. Each was accompanied by Argentine and Chilian representatives; and, in case of a critical discussion as to the exact site of any pillar, he was either to decide the question himself or (if he considered it of primary importance) he was to refer the point to me as chief arbitrator and representative of the tribunal.

With such energy and determination did all the party set to work—clearing roads through the forests, building boats for the lakes, climbing peaks for the purpose of a better outlook, and finally hauling the iron framework of the pillars into position over inconceivably rough ground—that the whole line was demarcated, marked, plotted on the maps, tabulated and reported on, without a single hitch, a month before I had reckoned that it could possibly be done.

I settled personally a small portion in the extreme south, which promised to give rise to local difficulties; for the rest I have to thank my assistants (Capts. Robertson, Thompson, Dickson, and Crosthwait, and my son, Lieut. Holdich) and a party of most capable and energetic engineers drawn from many sources, for their splendid services and loyal co-operation.

The accompanying illustrations will give some idea of the nature of the country with which we had to deal.

PAPER VIII.

RADIUM.

BY

FREDERICK SODDY, Esq., M.A.

(Lecture delivered at the School of Military Engineering, Chatham, on 14th January, 1904).

RADIUM.

RADIUM is the name given to a new chemical element by its discoverer, Madame Curie, a Polish lady working in Paris. It is characterised, as its name implies, by the power of giving out rays continuously and spontaneously without receiving any stimulus, so far as we know, from the outside. This self-radiance or, as it is usually known to the scientist, this *radio-activity* is a characteristic of the element in whatever compound or condition it exists; and, for any given quantity of the element it can neither be increased nor diminished by the action of any agency or force with which we are at present acquainted.

Uranium. Radium, although it is almost beyond comparison the most powerful radio-active element, is not the only one. The property was accidentally discovered for the element *uranium* by M. Henri Becquerel of Paris in 1896 in the following way. It was just after the discovery of the X-rays by Röntgen; and the rays given out by subsequently discovered radio-active substances, which are frequently called Becquerel rays in honour of their first discoverer, resemble at least superficially the X-rays; thus they are able to penetrate thin sheets of metals and other bodies opaque to light, and although invisible to the unaided eye they readily impress a photographic plate. Becquerel found that the compounds of the element uranium darken a photographic plate through thin sheets of copper and aluminium foil, that this action is common to all the compounds of uranium even when they have never been exposed to light, and that this power is possessed unaltered by the compounds after they have been kept in complete darkness for many years.

Thorium. Shortly afterwards it was found that another element, viz., *thorium*, possessed the same power as uranium to about the same degree.

The photographic test was the first to be used in the examination of the new property, but it was soon found that there was for the rays another and infinitely more delicate test, which allowed also of measurements being made with a considerable degree of certainty. This is the power possessed both by the X-rays and by those we are here more nearly concerned with of discharging an electrified body. If a gold-leaf electroscope is charged with electricity, the leaves repel each other and stand out from the support from which they hang in the form of an inverted V. If now any radio-active substance is brought into the case of the electroscope, the electricity on the leaves is discharged and the leaves collapse. This is due to the rays, in their passage through the air, making the latter a partial conductor of electricity. Under ordinary circumstances the air is a perfect insulator, so that the leaves of a properly constructed electroscope, when once charged, will remain so in ordinary air for many hours or even days without collapsing. When the air, however, is exposed to the rays in question it rapidly conducts the electricity from the leaves; and the rate at which the latter collapse furnishes a means, at once sensitive and accurate, of measuring the intensity of the radiation from any particular substance.

Pitchblende. Mme. Curie in this manner obtained the first hint of the existence of a more powerfully radio-active element than either uranium or thorium; for she found that a certain mineral, *pitchblende*, which occurs naturally in the earth's crust, discharged an electroscope more rapidly, and affected a photographic plate in a shorter time, than any other body known. Pitchblende contains much uranium, but the uranium therein would only account for a small fraction of the radio-activity. Hence she set about, by the ordinary methods of chemical analysis, to separate the pitchblende into its constituent elements, each of which she examined in turn for the property of radio-activity. She found that the small quantity of *barium* in pitchblende was always very strongly radio-active, nearly a hundred times more so than uranium or thorium. Now ordinary barium is not at all radio-active; and she rightly concluded that there was present in pitchblende a new element, similar to barium in its chemical nature, but distinct from it, and that the high activity of the barium obtained from pitchblende was due to its admixture with a small quantity of the new element. The actual quantity present proved, however, to be very small, and radium so closely resembles barium in its nature that the process of separating the two elements by chemical means was very tedious and laborious.

After several years' work, having worked up many *tons* of pitch-blende, she finally succeeded in obtaining a few thousandths of an ounce of the chloride of the new element in a pure state. Its radio-activity proved to be at least a million times stronger than that of uranium ; it possessed a very distinct and characteristic spectrum ; and its atomic weight, viz., 225, was much higher than that of barium, which is 137 (hydrogen being considered unity). The atomic weight of thorium is 232 and that of uranium 240 ; so the three elements which are unique in being radio-active are also unique in possessing the heaviest atoms of all the elements. Radium.

But it is the extraordinarily powerful radio-activity of radium, when its compounds are got in the pure state, that gives the element its main interest. The rays are invisible to the unaided eye ; but they are so powerful that, like the X-rays, when they impinge upon certain substances they cause them to fluoresce brightly with visible light. They can thus be made to all intents visible to the eye. Of fluorescent substances the platino-cyanides of barium, calcium, etc., an artificial zinc sulphide (known as Sidot's hexagonal blende), the mineral zinc silicate (also known as willemite) and the diamond are the most suitable for the purpose. With a thousandth of an ounce of a radium compound some very striking and beautiful effects can be produced by the aid of these substances in a darkened room.

The really wonderful feature about radium is the spontaneity and permanence of its radiations. To produce light, as in making a body fluoresce, energy is required ; and this energy is furnished in comparatively large amounts by a tiny quantity of radium, year after year, without diminution and without drawing upon any external reservoir of energy or being stimulated in any way from the outside.

At the commencement it looked as if radium upsets some of the fundamental ideas in science with regard to the conservation of energy and the impossibility of obtaining work without a corresponding change in the matter from which it is derived. This we shall see is not the case ; but the explanation of the source of energy of radium has already led to a great extension of our knowledge of the nature of matter, and has revealed vast stores of energy which have hitherto been allowed to remain untapped and unsuspected. The energy given out by radium was brought forcibly before the imagination by the discovery last year, by MM. Curie and Laborde, that radium maintains itself at a temperature appreciably hotter than its surroundings. This is not difficult to understand, for it is well known that energy of any kind, when it meets with resistance, is converted to heat; when the rays from radium are stopped by any obstacle, and the matter of the radium itself stops a large part of the rays, their energy appears as heat. Radium gives out every hour enough heat to raise its own weight of water from the freezing to the boiling point; in less than two days it evolves as much energy as would be evolved by the explosion of an equal weight of the most powerful explosive we possess; yet this energy is given out, not for any special hour or day, but year after year, at a rate which remains constant and shows no appreciable diminution.

Radio-Active Change.

The explanation is to be found in the view developed by Rutherford and Soddy in Montreal about eighteen months ago, as the result of a long series of investigations begun by Professor Rutherford some four years previously and continued uninterruptedly ever since. From this work it has been proved that the radium is undergoing a change, but so excessively slowly that many years or even centuries would be required before the quantity of any given amount of radium suffered appreciable diminution; probably about one two-thousandth part of the whole changes every year. Uranium and thorium are changing in an exactly analogous manner, but a million times more slowly. So these elements would survive geological epochs of time without appreciable diminution in quantity.

The point is that the change suffered by the radio-elements, as they are termed, is of a different kind from any change that has been known before; it is nothing less than the change of the atom of the element, which in consequence is undergoing a process of natural transmutation into other elements. It is well known that no change we are acquainted with will transmute one element into another, as for example silver into gold; the task is impossible for man, but not so for Nature. The atoms of the heaviest elements, radium, uranium and thorium, are slowly disintegrating or exploding; the explosion is absolutely instantaneous so far as any one atom is concerned, and occurs at a definite instant in its life's history; but in any collection of atoms by no means all of them break up at the same instant; a few explode during one second, and another set the next second, a constant fraction of the total number present changing in this manner in each unit of time. In accordance with the general fitness of things, which has placed the power of breaking an atom up, or of putting it together, entirely beyond the domain of things that man can accomplish, it is equally beyond his power, when an atom does break up by natural causes, to stop it breaking up or to make it break up more rapidly than it otherwise would; the radio-activity of any given quantity of matter can neither be increased or diminished by any agency with which we are acquainted.

It is doubtful whether this interpretation would ever have been arrived at but for one striking feature of the process of disintegration. An atom like radium does not explode once only, but goes through a fixed number of successive disintegrations in regular order. The simplest mental picture that can be obtained of the process is to regard the radium atom as being built like a shell, but with several charges of explosive—four at least—instead of one only. Each of these charges detonates in regular order at certain definite rates, and the explosion of each charge takes place without affecting the remaining charges. What happens when the first charge of a radium atom goes off? We may suppose (see *Plate*) that it blows one corner of the atom into fragments, leaving three-fourths of the atom, containing three unexploded charges intact. What then are the fragments, and what the maimed atom?

α, β and γ Rays.

The answer to the first question is to be found in some profound investigations that have been made on the nature of the rays from radium and the other radio-elements. The rays have been shown to be of three kinds, which may be distinguished from one another by their penetrating power. These are known as the α, β, and γ-rays, the former being the least and the latter the most penetrating. The α-rays will hardly penetrate a single thickness of paper, and are stopped by passage through less than an inch of air; they are the least striking at first sight, but prove to be by far the most important, for they are responsible for at least 99 per cent. of the total energy emitted by the radium. The β-rays pass readily through thin sheets of copper, aluminium and even lead; but can be completely stopped by a fraction of an inch thickness of these metals. The γ-rays are in some ways the most remarkable, for they penetrate with ease more than an inch of lead and several inches of steel.

As to the nature of the three kinds, the γ-rays, to commence with the least important, are probably a sort of X-ray of very high penetrating power—that is, a sudden short wave in the ether, transmitted like a light wave, but differing from it in being composed of a series of disconnected and sudden pulses rather than a succession of regular undulations. They are probably a secondary wave produced from the second type, the β-ray, at the moment when it is emitted.

The β-rays are interesting because they are similar in kind to a long-known species, the cathode-ray, which, under the name "radiant matter," was investigated thirty years ago by Sir William Crookes. They are produced when an electric discharge passes through a very highly exhausted bulb or "Crookes' tube." They have been shown by Professor J. J. Thomson not to be rays at all in the ordinary sense of waves in the ether, but to be rather a flight at enormous speed of tiny particles, each charged with negative electricity. The particle is a thousand times smaller than any that are known to the chemist, whose unit is the hydrogen atom. It is suggested that they are "atoms" of electricity, practically, if not completely, disembodied from matter. Becquerel has shown that the β-rays are in reality cathode-rays, but travelling with a far higher velocity than those obtainable from a Crookes tube, and attaining in certain cases a speed almost equal to that of light—180,000 miles a second. The evidence for this view cannot be fully discussed here, but it depends mainly on the fact that the β-rays and the cathode-rays are deflected by means of a magnet from the straight lines in which they travel.

Mass of α Particle.

An analogy may assist in showing how this result has been arrived at. Imagine a projectile fired horizontally from a height. Under the constant force of gravity the path of the projectile suffers deviation towards the earth. The extent of the deviation will depend on the velocity. If the deviation of the path of the projectile from the straight line were measured, then, since the force of gravity is known, the velocity could be calculated. An electrically charged particle, moving at right angles to the lines of force in a magnetic field, suffers deviation in the same way as a projectile moving at right angles to the force of gravity; but the extent of deviation will depend on the mass of the particle and the value of its charge as well as upon its velocity. If the deviation suffered in a magnetic field of known strength is measured, the momentum of the particle can be calculated, provided the value of the charge is known. There is strong evidence for supposing that the value of the charge carried by both the α and the β radiant-particles is the same and is equal to the invariable "atomic charge." Now a charged particle suffers deviation from its path by electrical as well as by magnetic forces, and the electrical deviation does *not* depend on the velocity of the particle. If the value of the charge and the strength of the electrical force deviating the particle is known, the mass of the particle can be found. Combining this value with that of the momentum deduced from the magnetic deviability, the velocity of the particle may be calculated.

The α-rays are the most important because they possess practically all the energy emitted. It was shown about a year ago by Rutherford that the α-rays also are not really waves but particles projected with enormous velocity; they differ from the β-rays in that, in the first place, their particles are positively instead of negatively charged and, in the second, the size of their particle is about a thousand times larger, being equal to or slightly greater than the hydrogen atom. Their speed is somewhat less than that of the β-rays, being about 20,000 miles a second; but their energy, on account of their greater mass, is far higher than in the case of the β-ray. The deviation suffered by the α-particle is about a thousand times less than in the case of the β-particle, and its experimental measurement by Rutherford was a feat requiring great skill and resource. The view that the α-particle is of much larger dimensions than the β-particle is borne out by their respective powers of penetrating matter. The latter, being so much smaller than the atom, are able to find their way through considerable thicknesses of matter with great ease; the α-particles, on the other hand, although their kinetic energy is much greater, are stopped by very much smaller thicknesses of matter. The β-particle can probably thread its way among the interstices of an atom and pass clean through it, under circumstances where the α-particle would collide and be stopped.

The α-ray particles then are the fragments of the radium atom, the corner of the shell blown off when it disintegrates. They consist of little atoms, about the size of the hydrogen atom, expelled from the big radium atom with terrific energy by a sudden internal cataclysm. In some cases, though not in the particular one we are now studying, viz., the first disintegration of the radium atom, the tiny β-ray particle is expelled as well; as a rule, however, these do not appear till the last disintegration. The residue of the atom, which still contains three unexploded charges, remains to be considered.

Radio-Active Emanation.

In addition to giving three kinds of rays, radium also exhibits a most extraordinary property. It is continually manufacturing out of itself, at a constant rate, an entirely different kind of matter, called the "radio-active emanation." As its name implies, it is volatile or gaseous in character, and continually emanates from the radium compound and diffuses away through the air. It cannot be perceived by any direct test, as its quantity is too small; but it gives out rays on its own account, which enable it to be traced and detected with ease. The rays are again α-rays, similar to those produced from the radium itself, and these, in spite of the fact that the actual amount of emanation is only an infinitesimally small quantity, are given out in such intensity that the emanation in a glass tube will keep fluorescent bodies like willemite brilliantly luminous in the same way or even more strikingly than radium itself. This emanation consists of the partly disintegrated atoms of radium, and the α-rays it gives are due to the second charge of the shell going off and blowing the second quarter of the atom into fragments about the size of the hydrogen atom.

Note the difference, however, between the radium and the emanation. The former goes on for years giving undiminished radiations, but those coming from the emanation, when the latter is separated from the radium producing it and left to itself, for example in a sealed glass tube, rapidly diminish in intensity in the course of a few days and after a few weeks practically cease. If the radium from which the emanation was originally obtained is examined, it will be found to have manufactured a fresh crop of emanation as fast as the old decayed; and, when the latter has entirely ceased to exist as such, the amount obtainable from the radium is again just as great as at first. A little consideration will show that this must be so if the view that has been here developed is the correct one. The radium is breaking up very slowly; hence the number of partly-disintegrated radium (*i.e.*, emanation) atoms produced in the course of a few weeks must be comparatively few; certainly the quantity must be too small to be directly perceived. In order for it to be perceived at all the particles must break up very fast, so that a sufficient number of α particles are projected to be detected. This means that the amount of emanation must rapidly diminish when left to itself; and, since a fixed proportion break up per second, the number breaking up diminishes and the α particles projected become fewer, that is to say the radio-activity decays and finally disappears. On the other hand, while this has been taking place, more atoms of radium have gone through their first disintegration, and more atoms of the emanation are in consequence produced.

A definite and very small proportion of the total number of radium atoms break up into α-particles and emanation in the unit of time ; and a definite, but much larger, proportion of the emanation atoms break up similarly into more α-particles and a new body, which will be considered later.

Clearly a limit is set to the quantity of emanation that can accumulate from any given quantity of radium. This is reached when the number of emanation atoms breaking up per second equals the number produced per second from the break-up of the parent-radium. The proportion of the radium breaking up in the unit of time is about ten thousand times less than the proportion of emanation atoms breaking up in the same period. Hence the quantity of emanation accumulating, when the limiting or equilibrium value is attained, is only about one ten-thousandth part of the quantity of the radium ; this quantity, with the amount of radium at present available, is below the means of direct recognition.

The way it is recognised, namely by its radio-activity, may be likened to the way in which the impalpable quantity of a powerful scent like musk is detected. Air charged with the odour of musk could not by any direct chemical test be shown to contain any other constituent but ordinary air ; air containing the radium emanation is most powerfully radio-active, but it could not be shown by any direct chemical test to contain any constituent except ordinary air.

In spite of the radium emanation being a gas, and diffusing like a gas away from the radium producing it whenever the latter is exposed open to the air, yet in certain cases the emanation does not succeed in all escaping but some remains entangled or imprisoned within the radium compound. This never occurs if the compound is in the state of solution, but frequently does when it is in the dry solid state. The latter generally retains, stored up and unable to escape, a relatively large fraction of the emanation produced, even when the compound is freely exposed to dry air. Solution in water liberates instantaneously this stored-up emanation, and it passes into the air or gas above the solution.

Induced or Excited Activity.

What is formed from the emanation when it in turn disintegrates ? Obviously, if we still retain our former picture, an atom will be produced which now only contains two unexploded charges. There is still another property of radium which has not yet been mentioned. Any objects whatever, left in the neighbourhood of a radium compound, become in turn temporarily radio-active ; this was called by M. and Mme. Curie the "induced" activity, and by Rutherford the "excited" activity. The latter proved that the phenomenon was due to the deposition of a film of active matter on the object rendered radio-active; and this film, which is invisible and unweighable but strongly radio-active, is derived from the emanation diffusing away from the radium compound. If there is no emanation, as, for example, when the radium compound is in a completely sealed case, there is no activity "induced" or "excited" on the external objects.

This is again easily explained on the disintegration theory. The radium atom has certain properties. The radium atom, or rather the residue of it after it has once disintegrated, is a new element with entirely different properties; it is a gas. But the residue of the disintegration of the emanation, *i.e.*, the original atom with but two charges left, is again completely different from the emanation; it has changed again to a solid form of matter.

It is this solid form of matter which settles down on surrounding objects from the gaseous emanation and gives rise to the phenomenon of "induced" activity. Its rays are those produced in the third and fourth disintegrations; for it is known that two changes occur in this matter after it has been deposited, although the intermediate stage, the atom with but one charge of explosive remaining, has not yet been obtained by itself. These last changes occur very rapidly and are completed in the course of a few hours.

In these last changes the β and γ rays, as well as α-rays, are produced. If the object so rendered temporarily radio-active is scrubbed with sandpaper, the active deposit is removed to the paper to a greater or less extent. Again, if it is treated with certain acids, the active deposit can be dissolved off; and on evaporating the acid, the activity is left behind on the vessel in which the evaporation is carried out. These properties show that there is an actual film of non-volatile matter which causes the activity. Lastly, if the object is heated to a sufficiently high temperature—above a red heat—the film is volatilised and again re-deposited on any cold object in the neighbourhood; the original object is rendered non-radio-active and the induced or excited activity is transferred to surrounding objects.

Now it will be noticed that in all these cases the matter itself has never been in sufficient quantity to be seen or weighed; and we rely on the rays it gives during its further disintegration in order to investigate and detect it. When the disintegration process is completely finished, some products remain, and the question arises as to what they are. It will be seen at once that the extremely small quantity which is produced puts a very great difficulty in the way of their further examination, for we have no means by which such small quantities can be detected. Nature herself, however, gave the clue to the answer of this question. The final products are by definition not changing; hence in their case there is no limiting or equilibrium quantity, regulating the amount which can accumulate. Time, and time only, is needed for this amount to attain a value within our powers of direct recognition. In the natural minerals, in which the radio-elements are found, it is obvious that the final products of the disintegration must have been steadily accumulating through past ages, and hence it is not unreasonable to suppose that the minerals will invariably contain appreciable quantities of these products. An examination of the minerals containing the radio-elements gives support to the view that one at least of the elements found therein is actually one of the products of the disintegration of the radio-elements, and has been steadily produced in former ages by their break-up.

This element is *helium*, which has had a somewhat eventful history in science. In 1868 Sir Norman Lockyer observed in the spectrum of the sun's chromosphere, very near to the double yellow line of sodium, a yellow line which he denoted as D_3; as its presence could not be due to any known element, he surmised that it was due to a solar element not present on the earth; he gave it the name helium. In 1895 Sir William Ramsay discovered a new gas, giving the D_3 line among six others in the uranium and thorium minerals, and this gas is undoubtedly the cause of that line in the sun's spectrum; he pointed out the curious fact that it was only present in minerals which contain these two elements, to which we can now add radium. Now helium is marked chemically by a complete inertness; it forms no compounds whatever, and has never been condensed into the liquid or solid form; the state in which it existed in the minerals which contain it was a mystery. From this evidence Rutherford and Soddy put forward the suggestion that it had been formed *in* the mineral during past ages by radioactive changes, and had been retained because it was mechanically prevented from escaping. In July of last year the writer, in conjunction with Sir William Ramsay, proved experimentally that helium was being produced from radium in very small amounts, and thus verified the earlier prediction. The spectrum reaction, especially as regards the D_3 line, is so delicate that an excessively Helium.

small quantity of the element can by its aid be detected with certainty. We also watched the gradual growth of the helium spectrum in a sealed up glass tube, into which only the radium emanation had been at first put, thus showing that helium is certainly a product of the second, third, or fourth disintegration. Whether it is also produced in the first is not known; neither is it known exactly what it is which is helium. It may be that some of the fragments expelled as α-rays are in reality atoms of helium, or possibly it is produced when the last disintegration of the radium atom occurs. Finally it must be pointed out that it is by no means likely that helium is the only element produced in this way, and that probably in the course of time others also will be detected. The difficulty is the minuteness of the quantity.

Summary. The foregoing conclusions may now be epitomised. In any mass of a dry solid radium compound there will usually be not only radium but all three of its radio-active disintegration products. Only a small part of the α-rays—about 25 per cent. of the whole—are due to the radium atoms; the remaining three-fourths are due to the disintegration of the emanation and of the products of its disintegration. The α-rays being very feebly penetrating, only a small fraction escape absorption in the mass of the material. The energy of those absorbed is converted into heat, and the compound maintains itself in consequence a few degrees above the surrounding temperature. Equilibrium between the quantities of the radium and its disintegration products is attained in about three weeks after preparation of the compound in the solid state, and then the radio-activity and the heat emission of the compound is at a maximum. If the compound is dissolved in water, the imprisoned emanation escapes into the air and the radio-activity is divided into two parts—(1) that due to the emanation in the air, (2) that remaining with the radium. The latter consists partly of the α radiation, due to the initial disintegration of the radium (about 25 per cent. of the total) and known as the non-separable activity, and partly of the α, β and γ radiation derived from the matter causing the excited activity which has been produced from the emanation while it was stored in the radium; the activity due to the emanation consists only of α-rays and equals about 40 per cent. of the total; the α, β and γ radiation of the excited activity contributes the remaining 35 per cent. The changes of the matter causing this activity are very rapid and are completed in a few hours. Hence, if the radium solution be evaporated to dryness immediately it is dissolved and its activity measured, it will consist at first of α, β and γ rays due to the non-separable radio-activity (25 per cent.) and of the excited activity (35 per cent.), and therefore will equal 60 per cent. of the initial activity. The activity of the emanation separated will at first correspond to 40 per cent. of the total; after a few hours the excited activity in the radium disappears; the activity in consequence falls to 25 per cent. and now consists only of α-rays. But in this time the emanation, if it be stored in a closed vessel, has produced a new crop of the excited activity matter on the walls of the vessel. Its activity therefore rises in a few hours from 40 to 75 per cent., and now consists of α, β and γ rays instead of only α-rays as at first; if now the emanation is blown out of the old vessel into a new vessel, the excited activity matter is left on the walls of the old vessel, and with it all the β and γ radio-activity and 35 per cent. of the α radio-activity; only the 40 per cent. of the latter due to the emanation is transferred. Then in the course of another few hours another fresh crop of excited activity matter is deposited as a film on the walls of the new vessel, which now shows α, β and γ radio-activity, while the excited activity on the walls of the old vessel has completely decayed.

Now consider the radium, and the emanation from it, over a further course of a few weeks. The activity of the emanation slowly decays, and concomitantly the excited activity produced from it grows less. The radium on the other hand generates a fresh crop of emanation which is stored up in the solid compound, and the stored up emanation produces a corresponding crop of excited activity matter. Hence the activity of the radium, after solution and immediate evaporation to dryness, is at first 60 per cent. of the initial and comprises α, β and γ radiations; after a few hours it falls to 25 per cent., consisting only of α-rays; after a few weeks it is again 100 per cent., and again comprises α, β and γ rays. The activity of the separated emanation, on the other hand, is at first 40 per cent. of the original and comprises only α-rays; after a few hours it has risen to 75 per cent. of the initial and comprises α, β and γ rays; in the course of a few weeks it has decayed to nothing, the α, β and γ rays disappearing in the same proportion.

The whole of this complicated series of changes, which result from the simple solution of a dry solid radium compound in water and which follow necessarily if the disintegration theory is true, are borne out in the minutest detail when the experiment is performed in the laboratory. A thin sealed-up glass tube, originally containing pure radium, in the course of a few thousand years would contain nothing but the ultimate inactive products, and the outside space would contain the matter which in the form of radiant-particles constitutes the α and β rays of radium. The question will be asked "How is it that there is any radium left?" The answer made by the disintegration theory is that probably, just as helium is "grown" by the radium, so also radium "grows" by the slow disintegration of one of the heavier elements present in pitchblende. After the radium in the glass tube had disappeared, the pitchblende from which it was originally obtained would contain a new crop equal to that initially separated. This is, however, at present an unverified prediction.

Internal Atomic Energy.

One aspect in the nature of the disintegration of the atom remains to be considered, and that is the energy evolved during the process. It is easy to see that since radium evolves such a large amount of energy by the change of a relatively insignificant fraction of its substance, the energy evolved year after year must make an enormous total. It is possible to calculate what the energy evolved in the *complete* disintegration of a gram of radium must be, although, as several thousand years must elapse before the process is completed, it cannot be experimentally measured. Rutherford has estimated that the energy given out by one gram of radium during its complete life would raise a weight of 500 tons a mile high; it is of the order of a million times greater than is ever given out by a similar weight of matter undergoing ordinary chemical change.* This store of "internal atomic energy" we know of for radium because it is breaking up; we have no means of recognising it for other elements which do not happen to be breaking up. But it is probable that all heavy matter possesses—latent, and bound up with the structure of its atom—a similar quantity of energy to that possessed by radium. If it could be tapped, and controlled, what an agent it would become in shaping the world's destiny! The man who first put his hand upon the

* An experimental determination of this quantity has now been obtained by Sir William Ramsay and the writer. The quantity of radium is diminished to one-half the initial after the lapse of about one thousand years. The energy liberated by radium during its complete change is, weight for weight, about 300,000 times that liberated from a mixture of hydrogen and oxygen when they explode to form water. The last explosive liberates more energy for a given weight of matter than any other known.

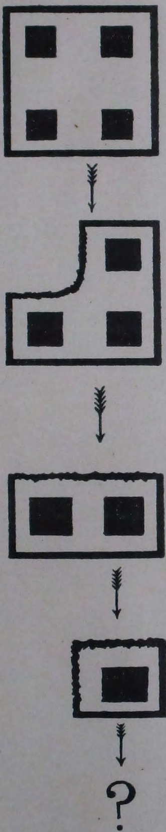
F.S.

1*st March*, 1904.

lever, by which a parsimonious nature regulates so jealously the output of this store of energy, would possess a weapon by which he could destroy the earth if he chose.

It is a comforting thought that we are a conservative system, subjected in the past to conditions more strenuous than it is at present possible to realise. The earth resembles a boiler that has been tested during mauufacture to higher pressures than can be subsequently generated. Hence, if the sudden evolution of the enormous stores of energy pent up in matter were a practical possibility, it is certain that it would have occurred already during the testing process that took place in the earlier history of the earth. The fact that we exist is a proof that it did not occur; that it has not occurred is the best possible assurance that it never will. We may trust Nature to guard her secret.

Disintegration of the Radium Atom.



RADIUM

THE EMANATION

MATTER NOT YET NAMED

Causing the induced or excited activity

DITTO.

?

(perhaps Helium)