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PREFACE.

THE Royal Engineers Institute Council having decided to issue, for the future, the *Professional Papers* in pamphlet form only, the present 6 Papers are the last to appear as a Volume.

Published first in quarto form, the *Professional Papers* were started in 1837 on the suggestion of Lieut. (afterwards Sir W.) Denison, R.E. In 1851 they were altered to Royal Octavo and again in 1877 to Demy Octavo, appearing annually until 1905.

In that year the alteration in the form of the *R.E. Journal* led to a corresponding change in the *Professional Papers* which were again henceforth issued in Royal Octavo but in pamphlet form only. It was, however, decided at the time to publish the combined papers in a Volume from time to time for the few Officers who still desired them in that form.

This practice is now to be discontinued, and Vol. II. of the New Series concludes therefore the long list of bound Volumes of the *Royal Engineers Professional Papers*.

W. A. HARRISON,
Major,
Sec., R.E. Institute.

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PROFESSIONAL PAPERS.—FOURTH SERIES.

VOL. II.—No. 1.

THE THEORY OF ARCHED MASONRY DAMS.

BY

Capt. A. ff. GARRETT, R.E.

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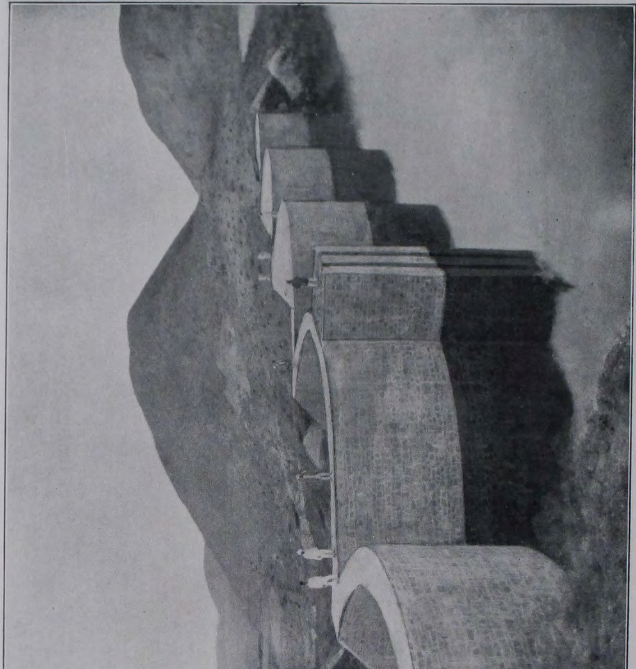
PREFACE.

1. The greater part of the theoretical matter which is given below was worked out in 1903, and published by the Government of India as Technical Paper No. 170. Since then, however, various criticisms have been received, and the whole Paper has now been revised in accordance with the suggestions which have from time to time been made to the author.

2. In 1905, an arched dam, 60 feet high, with five spans of 85 feet and four piers, was constructed by the author in the Alwar State of Rajputana, with a saving of 30 per cent. on the cost of an ordinary masonry dam of the gravity type. The design for another arched dam, 120 feet high, of 120 feet radius and 200 feet span, is now being submitted to the Government of India for sanction, near Quetta, in Baluchistan, and the estimates show a saving of 1,25,000 rupees over the ordinary type of dam, while the design of another dam on these principles is under consideration in the Kotah State in Central India.

3. A brief account of the Alwar dam is added in an appendix.

AR, ON THE GARRETT PRINCIPLE.



THE THEORY OF ARCHED MASONRY DAMS.

1. The investigation of the theory of masonry dams has attracted the attention of eminent engineers for many years past, and the close agreement of the profiles worked out by Rankine, Molesworth, and Wegman appear to indicate that any further appreciable economy in the construction of dams of the ordinary type cannot be hoped for. Wegman has gone into the matter very thoroughly, and has worked out profiles for all heights and specific gravities of the masonry, and his results probably indicate the most economical construction of the ordinary straight form of dam that it is possible to attain.

2. In this Paper what is believed to be a new method of dam construction is described, and the economy of the results, amounting to savings on the ordinary type of dam of from 16 to 39 per cent. in the quantity of masonry in the case of dams up to 150 feet in height, is in itself a sufficient reason for a careful enquiry into its possibilities. Briefly the method is this—to break up a dam into a series of horizontal arches of short span supported by suitable piers, the convex faces of the arches facing upstream.

3. Arched dams are comparatively rare structures, and appear to be looked on with disfavour by most engineers, who have stated that the arched principle is only applicable to low dams across narrow gorges, and that therefore the opportunities for their practical construction will be rare.

It is perhaps on account of these adverse opinions that the subject of arched masonry dams has been neglected. In most standard works the subject is dismissed with a few words.

Tudsbery and Brightmore, in their book on Waterworks Engineering, give a formula for the thickness of the masonry at any given depth below the surface of the water, but pursue the matter no further.

4. The Committee, appointed to investigate the proposed Quaker bridge dam in America, give a few general conclusions regarding arched dams, which may be quoted here.

"In designing a dam to close a deep, narrow gorge, it is safe to give a curved form in plan, and to rely on arch action for its stability; if the radius is short, the cross section of the dam may be reduced below what is termed the gravity section, meaning thereby a cross section, or profile, of such dimensions that it is safe, by the force of gravity alone, to resist the forces tending to overturn it, or to slide it on its base at any point."

"A gravity dam built in plan on a curve of long radius derives no appreciable aid from arch action."

"The division between what may be called a long radius and a short radius is, of course, indefinite, and depends somewhat on the height of the dam. In a general way we would speak of a radius under 300 feet as a short one, and a radius of over 600 feet as a long one, for a dam of the height contemplated."*

"The curved form better adapts itself to changes of volume due to changes of temperature."

5. The above is borne out by the investigation which follows. For radii greater than 250 to 300 feet the thickness of the masonry required to resist the crushing stress, considering the structure as an arch, frequently works out as greater than the thickness required, treating the structure as an ordinary gravity dam.

6. It is evident that the greater the radius, the less arch action can be relied on to give stability, and attempts have been made by Bachman, Lieckfeldt, and others to compute what proportion of the load is taken up by arch action, and what proportion is resisted by the mere weight of a long arched dam. These calculations, however, rest on data which are little better than pure assumption. But there can be little doubt that arch rings of the radii here proposed, viz., 50 to 80 feet, will resist the water load by pure arch action, and the computations which follow rest on this supposition.

7. Messrs. Turner, Tudsbery, and Brightmore, in their book on Waterworks Engineering, state that there are only three arched dams existing, in which the requisite stability against the water pressure is attained by arch action, and not by the dead weight of the masonry.

These are† :—

(1). The Zola dam near Aix in Provence.
(2). The Sweetwater dam in California.
(3). The Bear Valley dam in California.

The dimensions of the last two are as follows :—

	Height.	Radius at top.	Top breadth.	Bottom breadth.	Date.
Sweetwater dam...	90′	220′	12′	46′	1888
Bear Valley dam...	64′	335′	$2\frac{1}{2}$′	22′	1894

* 240 feet.

† A description of another arched dam at Barossa, in South Australia, will be found in *Engineering News*, Vol. LI., page 321, dated 7th April, 1904.

8. In the Sweetwater dam the maximum compressive stress, calculated by (4) in paragraph 12, works out to $13\frac{1}{2}$ tons per square foot, and in the Bear Valley dam, to the remarkably high figure of 53 tons per square foot.* The latter is built of a rough ashlar granite facing, with a hearting of coursed granite rubble, all in cement. Even so, this high stress would be considered unsafe in any ordinary structure, yet, as far as I have been able to ascertain, the Bear Valley dam shows no signs of failure, though some of the joints are said to have opened out a little.

9. To these three arched dams must be added a fourth, to which my attention was called while I was writing this Paper.

This is the Meer Allum dam near Hyderabad. A plan of this, taken from *Indian Engineering*, is given in *Plate* V.

The dam is about half a mile long, and consists of twenty-one arches ranging from 70 feet to 147 feet in span. The Plate shows one of the 147-foot spans.

The dam is said to have been built about 1800.

There is a waste weir at one end, but during heavy floods water overflows throughout the whole length of the dam. It will be seen that this dam is very much on the principle advocated in this Paper.

It works out, however, as more expensive than a gravity dam, but is interesting as showing that the proposed method of construction as described in this Paper is quite practical.

The maximum compressive stress in the arch is about 11 tons per square foot. Another interesting point is that the resultant cuts the base of the piers within 5 feet of the downstream edge (see the section on AB), but it is doubtful if there is any tension on the upstream face, as the portions of the arch rings near the piers form practically a part of the piers, and must largely increase their stability.

10. The calculations which follow depend on the two following assumptions :—

(*a*). That the whole water thrust is resisted in the arch ring by arch action pure and simple, and it seems that this assumption is justifiable for the small radii, 50 to 80 feet, recommended.

Thus the question is freed from the composition of the water thrust with the vertical pressure due to the weight of the masonry in the arch.

(*b*). That the masonry behaves as an elastic solid.

* The stress occurs at 48 feet below the crest, where the dam is only $8\frac{1}{2}$ feet thick.

This is not true in actual practice, but is an assumption usually made in the design of masonry structures in default of any more reliable hypothesis.

From this it follows that at any joint the stress varies uniformly from a maximum at one edge or face to a minimum at the other.

11. Consider a horizontal arch acted on by water pressure on the convex side (*Fig.* 1, *Plate* VI.).

Let AB represent a horizontal section of such an arch at a depth d below the surface of the water, and let the water pressure at depth d be p.

Let r=radius of the arch=OA or OB.

Consider an element CD of this arch subtending an angle $d\theta$ at the centre O. The forces acting on the element are :—

(1). The resultant water pressure P acting radially as shown. This is the resultant of the water pressure p acting radially at every point on the circumference from C to D. It is easily seen that in the limit

$$P = prd\theta \qquad \text{.............................(1).}$$

(2). The reaction RR due to the compressive stress in the arch ring acting at each end of the element CD. It is evident from the symmetry of the figure that these two reactions are equal.

Resolving parallel to P, we have

$$P = 2R \sin \frac{d\theta}{2},$$

or

$$prd\theta = 2R \sin \frac{d\theta}{2};$$

whence

$$R = pr \qquad \text{................................(2).}$$

Hence the compression in the arch ring is constant, and everywhere equal to pr.

12. The manner in which this force is distributed throughout the thickness of the arch ring is probably not known, and certain assumptions must be made. Assuming that the intensity of the stress varies uniformly from face to face of the arch, the following formula from Rankine's *Applied Mechanics*, p. 273, may be applied :—

$$\frac{\sigma}{\sigma_1} = \frac{2r}{r + r_1} \qquad \text{.............................(3),}$$

where σ=maximum permissible compressive stress,

σ_1=average stress throughout the thickness t of the arch ring,

r=the outer radius of the arch,

r_1=the inner radius of the arch ;

also, evidently

$$t=\frac{pr}{\sigma_1}=\frac{pr\cdot 2r}{\sigma(r+r_1)} \text{ from (3)},$$

and

$$r_1=r-t\,;$$

therefore

$$t=\frac{2pr^2}{\sigma(r+r_1)}=\frac{2pr^2}{\sigma(2r-t)}.$$

Solving this quadratic in t, we get

$$t=r\left(1-\sqrt{1-\frac{2p}{\sigma}}\right) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4).$$

This gives the thickness of the masonry at any horizontal section where the water pressure is p, and is the same equation as given by Tudsbery and Brightmore in their book on Waterworks Engineering.

13. Formula (4) is only applicable to cases where r is constant, and therefore where the upstream face of the dam is vertical. For high dams, however, it will evidently be an advantage to make the section of the arch ring symmetrical, as in the dam shown in *Plate* I. This makes the loading on the foundations symmetrical (when the reservoir is empty), and reduces the crushing stresses due to the weight of the masonry to a minimum.

Now, if ρ be the mean radius of such a symmetrical arch ring, ρ will be constant for all depths, and

$$r=\rho+\frac{t}{2}\,;$$

whence, from (4)—

$$t=\left(\rho+\frac{t}{2}\right)\left(1-\sqrt{1-\frac{2p}{\sigma}}\right);$$

whence

$$t=\rho\frac{\sigma}{p}\left(1-\sqrt{1-\frac{2p}{\sigma}}\right)^2 \quad\ldots\ldots\ldots\ldots\ldots\ldots(5).$$

For $\frac{\sigma}{p}\left(1-\sqrt{1-\frac{2p}{\sigma}}\right)^2$ write k; then the formula becomes

$$t=k\rho \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6).$$

In para. 24 will be found a Table giving the value of k for various depths and stresses.

14. THE ECONOMICAL ARCH (*Fig.* 2, *Plate* VI.).

Consider such a symmetrical arch ring ABC.

Let the mean radius OA or OC$=\rho$.

Let mean span AC$=s$, and angle AOC$=2\theta$.

Considering s as constant, it is required to find what value of θ will give the most economical arch.

From (5) the thickness of the masonry varies directly with ρ. Hence also the area A of the cross section of the arch ring varies with ρ, and we have

$$A=C\rho,$$

where C is a constant.

Now the quantity of masonry Q in the whole arch ring is

$$Q=2A\rho\theta=2C\rho^2\theta,$$

and

$$\rho=\frac{s}{2}\operatorname{cosec}\theta.$$

Therefore

$$Q=\frac{C\theta}{2}s^2\operatorname{cosec}^2\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots(7).$$

For a minimum we must have

$$\frac{dQ}{d\theta}=0.$$

Differentiating—

$$\operatorname{cosec}^2\theta-\theta\,.\,2\operatorname{cosec}\theta\,.\,\frac{\cos\theta}{\sin^2\theta}=0\,;$$

whence

$$\theta\cot\theta=\tfrac{1}{2},$$

and

$$\theta=66^\circ\,47'.$$

Hence the most economical arch has a central angle of 133° 34'. This, however, is assuming the thickness of the arch at the water surface to be zero. In practice it is of course necessary to make the top a few feet thick. This results in somewhat reducing the above angle, and it will be found that an angle of 120° will generally give very nearly the most economical construction, and, in the designs which follow, all the arches are made to this angle.

15. The piers which support the arches must now be considered. As the function of the arches is merely to transmit the water pressure to the piers, each pier has to withstand the resultant of all the water pressures on one arch and on one pier in a direction at right angles to the general line of the dam. All other components and reactions cancel one another.

Let S be one complete span measured from centre to centre of piers.

h = the height of the dam,

μ = the intensity in tons per square foot of the resultant water pressure on the whole span at the bottom of the pier.

v = the bottom width of a pier.

The horizontal water pressure at the bottom of the pier $= \cdot 02786hS$*

and $$v = \cdot 02786h\frac{S}{\mu} \quad \ldots\ldots\ldots\ldots\ldots\ldots(8).$$

This gives the bottom width of a pier.

16. Now consider a vertical section of a pier (*Fig.* 3, *Plate* VI.), which for the present may be supposed to be a right-angled triangle ABC of height h, and base BC $=b$.

The intensity of the water pressure at the bottom C is μ' tons per square foot.

And the intensity of this pressure diminishes uniformly from C to A. Therefore the resultant P acts at two-thirds the depth, and is equal to $\frac{\mu h}{2}$.

The forces acting on a vertical section are therefore

$$P = \frac{\mu h}{2},$$

$$W, \text{ the weight of the pier} = \frac{whb}{2},$$

where w = the weight of a cubic foot of masonry in tons.

According to a well-known theorem, R, the resultant of P and W, must cut the base within the centre third in order that there may be no tension on the face AC.

Let R cut the base in D. If D is in the limiting position, then BD $= \frac{1}{3}$ BC, and R will be parallel to AB, since its line of action passes through the centre of gravity of the triangle ABC.

Let angle ABC $= \chi$.

Then $$R \sin \chi = W = \frac{whb}{2},$$

$$R \cos \chi = P = \frac{\mu h}{2},$$

$$\tan \chi = \frac{h}{b}.$$

* Water pressure at depth $h = \frac{62 \cdot 4 \times h}{2240} = \cdot 02786h$ tons per square foot.

Whence we get

$$b=\sqrt{\frac{\mu h}{w}} \quad \text{.............................(9).}$$

or

$$b=47{\cdot}4\sqrt{\frac{\mu h}{w}},$$

if w is expressed in lbs. per cubic foot, instead of tons.

The quantity of masonry Q_1 in one pier is $\frac{hvb}{2}$, or

$$Q_1={\cdot}01393h^2S\sqrt{\frac{h}{\mu w}} \quad \text{.....................(10),}$$

on substituting for v and b the values given by Equations (8) and (9).

17. Now from (7) the quantity of masonry in an arch varies as the square of the mean span, while from (10) the quantity of masonry in a pier varies as the complete span. The complete span and the mean span will be nearly equal, and in a dam of given length the number of spans varies inversely as the length of the spans. Hence in a dam of given length, the total quantity of masonry in the arches varies very nearly as the length of the spans, while the total quantity of masonry in the piers remains constant, whatever the length of the spans.

Hence, generally, the shorter the spans, the more economical the dam will be.*

This argument assumes that the intensity of pressure, μ, remains constant, whereas from Equation (8)

$$\mu={\cdot}02786\,\frac{hS}{v},$$

so that, if μ remains constant, v must vary directly with S. This seems a reasonable assumption to make, and leads to simple formulæ and convenient dimensions. In the designs which follow, μ has been taken as 9 tons per square foot. This is a purely arbitrary value, but it gives suitable dimensions. If μ is considered as a variable, it is possible that a somewhat cheaper design might be worked out, as the

* Lieckfeldt making certain assumptions finds that the action of a dam as an arch is greater.

(1). With a constant central angle, the smaller the span.

(2). With a given span, the greater the curvature, and the higher the wall.

(3). The greater the thickness of the dam at the summit.

(See *Centralblatt der Baewerwalting*, 1899, p. 301).

It will be seen that these conditions accord very fairly well with the most economical construction.

smallest practical span would not then be necessarily the most economical. But it is believed that the saving would be very small, and the formulæ would become more complicated.

However, in shortening the spans a practical limit is soon reached, for, with very short spans, the arch masonry becomes very thin. It will be found that complete spans of 90 to 150 feet give good practical results, with a mean radius of from 50 to 60 feet.

18. So far the piers have been considered as masses of masonry of which the section is a right-angled triangle. The masonry may, however, be further reduced by sloping the sides as shown in the Plates of designs for arched dams at the end of this paper. Sloping the sides has also the advantage of reducing the crushing stresses of the masonry due to its own weight. But if this form of pier be adopted, the rule of the centre third, and Equations (9) and (10) deduced therefrom, will no longer apply. Instead of a horizontal section of a pier being a rectangle, it will be a trapezium like ABCD (*Fig.* 4, *Plate* VI.).

Taking the condition that there must be no tension on the upstream face CD, we must assume that the stress varies uniformly from zero along the edge CD to its maximum along the edge AB.

Hence the problem of finding the centre of pressure (on the upstream side of which the resultant of the weight of the pier and the water pressure must lie) is the same as finding the centre of gravity of the figure shown in plan in *Fig.* 4 and in section in *Fig.* 5, *Plate* VI.

Let $CD = v$, $AB = e$, $OF = \text{unity}$,

$$v = ne.$$

Take axes Ox, Oy.

Then, by the general formula for centre of gravity, it may be shown that the distance of the centre of pressure from AB is equal to

$$\frac{\int_1^0 (1 + nx - x)(1 - x)\, x dx}{\int_1^0 (1 + nx - x)(1 - x)\, dx}$$

Evaluating this, the distance of the centre of pressure works out to

$$\frac{n+1}{2(n+2)}.$$

If the base OF be taken equal to b, then the distance of the centre of pressure from the downstream end is

$$\frac{b}{2}\frac{n+1}{n+2} \quad \text{.............................(11).}$$

19. The quantity of masonry in a pier of the above shape is

$$\frac{hb}{6}(v+2e) \quad \text{..........................(12).}$$

20. And the distance of the centre of gravity from the upstream face is

$$\frac{b}{4}\frac{n+3}{n+2} \quad \text{..............................(13).}$$

21. As these formulæ will frequently be required in designing piers, the following Table has been prepared, giving the distances (in decimals of the base b) of the centres of pressure and gravity from the downstream and upstream faces respectively.

TABLE GIVING DISTANCES FROM DOWNSTREAM AND UPSTREAM FACES OF CENTRES OF PRESSURE AND GRAVITY FOR SLOPING-SIDED PIERS.

n.	Distance of C.P.	Distance of C.G.	m.
1	·33	·33	47·4
1·5	·357	·321	54·6
2	·375	·3125	59·6
2·5	·389	·306	63·9
3	·4	·3	67
4	·417	·2917	71·7
6	·44	·2812	77·6
Infinite	·5	·25	82

$$b = m\sqrt{\frac{\mu h}{w}}.$$

μ = intensity of resultant water pressure on base of pier in tons per square foot.
w = weight cubic foot masonry in lbs.
h = height of dam in feet.

It may be shown that the greater the value of n, the greater the economy, but it does not seem advisable to make n greater than 3 or 4. Adopting a high value of n makes the pier unduly long and thin, and brings the greatest crushing stress to bear on a very thin edge. A value of n of about 3 seems to give the best results.

22. A formula for b, the length of the base of a sloping-sided pier, may be obtained as follows :—

If ABC (*Fig.* 3, *Plate* VI.) represent the section of such a pier, then in the limiting position of the resultant R, which gives no tension at C, the distance BD is equal to the distance in Column 2 of above table, and FC is equal to the distance in Column 3, this being the distance of the centre of gravity from the upstream face. Also EF is one-third the height of the dam or equal to $\frac{h}{3}$.

Now suppose $n=3$.

Then from above Table

$$BD = \cdot 4\ BC = \cdot 4b,\ FC = \cdot 3b,$$

whence $$DF = b\ (\cdot 6 - \cdot 3) = \cdot 3b.$$

Hence $$\frac{W}{P} = \frac{EF}{DF} = \frac{h}{3} \cdot \frac{10}{3b} = \frac{10}{9} \cdot \frac{h}{b},$$

and $$b = \frac{10}{9} \cdot \frac{hP}{W}.$$

The value of the numerical co-efficient of the right-hand member can similarly be found for any other value of n. Denoting this co-efficient by c, we have

$$b = \frac{chP}{W} \quad \text{.............................}(14).$$

Now $$P = \tfrac{1}{2}\ (62\cdot 5)\ h^2 S \quad \text{.......................}(15),$$

and if w be the weight of a cubic foot of masonry in pounds, we have from Equation (12)

$$W = \frac{whb}{6}\ (v + 2e)$$

$$= \frac{whbv}{6}\left(1 + \frac{2}{n}\right).$$

But from Equation (8), on substituting for v, we get

$$W = \frac{whb}{6}\left\{\cdot 02786 h \frac{S}{\mu}\left(1 + \frac{2}{n}\right)\right\}.$$

Hence, dividing Equation (15) by this expression, we get, after simplification and reduction,

$$\frac{P}{W} = 6724 \frac{n\mu}{bw\ (n+2)}.$$

But from Equation (14)

$$\frac{P}{W}=\frac{b}{ch},$$

so that

$$\frac{b}{ch}=\frac{6724n\mu}{bw\ (n+2)},$$

and

$$b=82\sqrt{\frac{chn\mu}{w\ (n+2)}}.$$

Writing m for

$$82\sqrt{\frac{cn}{n+2}},$$

we have

$$b=m\sqrt{\frac{h\mu}{w}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16).$$

The values of m corresponding to several values of n are given in the above table, so that the required length of the base of the pier can be very easily worked out.

23. Values of stresses. It now remains to consider the value to be adopted for the maximum permissible stresses in the arches and piers. Most dams are built of rubble masonry, and what follows applies to this class of masonry well laid in good lime mortar. It may be said that the values usually adopted vary between 6 and 9 tons per square foot. Professor Unwin has, however, stated that in his opinion he does not see why, in the case of strong mortar, considerably higher limits of crushing stress should not be adopted, and he goes on to say that in the case of the Quaker dam (above alluded to) a calculated stress of something like 16 tons per square foot had been allowed.

Now there are reasons for thinking that actually these calculated stresses may be largely exceeded.

No dam is perfectly watertight, and the result of percolation of water in a horizontal crack is to cause an upward pressure on the masonry, which will make the resultant of the water pressure and the weight of the dam fall nearer the outer face of the dam than intended, and so increase the stress at the outer face. Whether this often actually occurs to any serious extent it is impossible to determine, but there seems no doubt that percolation of water gives rise to a tendency of this kind. Lieut.-Colonel Scott-Moncrieff, R.E., very carefully investigated and reported upon the failure of the Bouzey dam in France, and it is noteworthy that the conclusion arrived at in this case was that the calculated stress at the back of the dam did not nearly represent the actual stress produced.

The dam gave way by tearing away of the joints at the upper face, and crushing of the stone on the lower; now the calculated stress where crushing took place was only some 4 tons per square foot, which should have been perfectly safe for the material of which the dam was composed.

But the resultant did not fall within the centre third, and probably a horizontal crack was opened out on the upstream face, with the result that the compressive stress on the downstream face was greatly increased and failure occurred.

It is probably partly because of the possible risks indicated above that modern engineering practice has fixed the limit as low as 8 or 9 tons. The actual crushing load of masonry varies from 100 to 150 tons for rubble up to 700 tons for granite masonry according to various authorities.

Now in the case of an arched dam the conditions are quite different as regards the arch ring. Horizontal cracks and percolation of water do not tend to increase the compressive stress in any way. There is therefore no danger of the calculated stresses being greatly exceeded. Not only this, but in the arch ring the masonry is probably as favourably situated to resist compression as it could be in any carefully devised experimental test. The load is applied perfectly uniformly and gradually as the water level gradually rises. Thus, granted fair homogeneity, which any ordinary care in construction should ensure, failure by distortion is well-nigh impossible, the arch ring can only fail by being absolutely crushed. Masonry is said to begin to crack at about half its ultimate crushing strength. If we take one-fourth the cracking limit as the safe working stress, this should be quite safe, and it would seem that a crushing stress of 12 to 20 tons or even higher (for good masonry) ought to be justifiable, and if arched dams are ever largely adopted, I believe that a stress of this amount will in future be considered perfectly safe. As stated above, the Bear Valley dam has withstood a stress of 53 tons per square foot for 13 years, and the mere fact of its success proves in what a favourable condition an arched dam must be to resist compression, and lends strong support to the views given above that a stress of from 12 to 20 tons per square foot should be quite safe for ordinary practice.

There is, however, not much advantage in adopting such a high stress limit for low dams, as this would result in very thin arches of large span, probably beyond the practical limit of safety. But in the case of dams over 60 feet in height a high permissible stress will result in a large saving in the lower courses of masonry.

In the piers there would seem to be much less danger of extensive percolation than in an ordinary straight dam, and consequently less risk of excessive stresses beyond the calculated values being developed. A stress up to 10 tons per square foot should be quite safe.

So far the extra stability afforded by the weight of the arches has been neglected. This is considered below in investigating the maximum compressive stress in the piers.

24. THE PRACTICAL DESIGN OF AN ARCHED DAM.

Divide up the length to be dammed into a series of spans; spans (measured from centre to centre of piers) of from 90 to 100 feet will give good results for dams up to 60 feet high. For higher dams rather larger spans may be adopted.

Let S be the complete span from centre to centre of piers in feet.

h, the height of the dam in feet.

v, the width of a pier in feet at the bottom.

r, the inner (or downstream) radius of the arch in feet.

ρ, the mean radius of the arch.

t, the thickness of the arch in feet at any depth d.

μ, the intensity of resultant water pressure at base of pier in tons per square foot; take $\mu=9$ (see para. 17).

The angle of the arch will be 120° for the reasons given above. Then

$$v = \cdot 02786 h \frac{S}{\mu} \quad \ldots\ldots (17).$$

$$r = (S - v)\,\tfrac{1}{2}\operatorname{cosec} 60^\circ$$

$$= \cdot 577\,(S - v) \quad \ldots\ldots (18).$$

$$\rho = \frac{2r}{2 - k_h} \quad \ldots\ldots (19).$$

$$t = k\rho \quad \ldots\ldots (20).$$

k is a co-efficient depending on the depth d, and σ, the maximum permissible stress in the arch ring.

Below is a Table giving the value of k.

In Formula (20) k_h denotes the value of k corresponding to h, and the value of σ adopted.

Let b = length of base of pier.

n = ratio of bottom width of pier to top width.

w = weight of a cubic foot of masonry in lbs.

Then
$$b = m\sqrt{\frac{h\mu}{w}} \quad \ldots\ldots (21).$$

The values of m corresponding to various values of n are given in the last column of the Table on p. 10. This formula entirely neglects the stability afforded by the weight of the arches.

TABLE OF VALUES OF k.

$t = k\rho$.

Depth.	Maximum Stress in Arch Ring σ.			
d.	9 tons.	12 tons.	15 tons.	20 tons.
20	·0660	...	...	...
25	·0840	...	...	...
30	·1026	·0748	·0590	...
35	·1219	·0886	·0696	...
40	·1420	·1026	·0804	...
45	·1629	·1170	·0914	...
50	·1846	·1319	·1026	·0750
55	·2073	·1473	·1141	·0831
60	·2311	·1629	·1259	·0914
65	·2560	·1791	·1380	·0998
70	·2820	·1959	·1503	·1084
75	·3094	·2133	·1629	·1171
80	·3385	·2312	·1758	·1259
85	·3692	·2497	·1891	·1349
90	·4017	·2691	·2027	·1440
95	·4363	·2889	·2167	·1533
100	·4733	·3096	·2311	·1628
105	·5133	·3312	·2459	·1725
110	·5567	·3536	·2611	·1824
115	...	·3770	·2767	·1925
120	...	·4017	·2929	·2027
125	...	...	·3097	·2131
130	...	·4547	·3271	·2237
135	...	...	·3448	·2346
140	...	·5134	·3629	·2459
145	...	...	·3818	·2575
150	...	·5789	·4017	·2696

25. Dams worked out by the above formulæ will be found to require considerably less masonry per foot-run than dams of the ordinary gravity type. The saving in the quantity of masonry will be about 30 per cent. for a 60-foot dam, with maximum stresses of 9 tons per square foot in both piers and arches, and about 20 per cent. for a 100-foot dam, if a stress of 15 tons per square foot is allowed in the arches.

But the above formulæ take no account of the extra stability due to the weight of the arches. In fact, the weight of the arches has been, so far, entirely neglected, and the piers have been calculated of sufficient stability to alone withstand the whole of the stress transmitted by the arches.

If the weight of the arches is taken into account, it is evident that the piers may be made much lighter. We must consider the forces acting on a pier and the two half-arches on each side as a whole, and investigate the stability of the whole. We must find the centre of gravity of the pier and of the two half-arches separately, combine them, and find the centre of gravity of the whole, then compound the total weight with the water thrust on the whole span, and investigate the stresses produced.

26. A design for a 100-foot dam is given in *Plate* I. The span from centre to centre of piers is taken as 125 feet, $\mu=9$ tons per square foot, and σ (the maximum stress in the arches) as 12 tons per square foot. Then by Formulæ (17), (18), and (19) we find

$$v=39 \text{ ft.},$$
$$r=49{\cdot}7 \text{ ft.},$$
$$\rho=58{\cdot}8 \text{ ft.},$$

and by Formula (20) the thickness of the arch ring is worked out for every 10 feet depth of water, and the resulting section of the arch ring is shown in *Plate* I. The thickness is taken as 5 feet as a minimum for the top 30 feet.

The cross-sectional area of the arch ring works out at 907 square feet, and with the central angle of the arch 120° and masonry weighing 140 lbs. per cubic foot, the weight of one arch is found to be 6,980 tons.

To find the centre of gravity of the arch,

Let 2θ = Central angle of arch,
ρ = Mean radius,
$2t_m$ = Mean thickness of the arch ring,
$\bar{y}$ = Distance of centre gravity from centre.

Then it may be shown that

$$\bar{y}=\frac{2}{3}\frac{\sin\theta}{\theta}\left\{\frac{(\rho+t_m)^3-(\rho-t_m)^3}{(\rho+t_m)^2-(\rho-t_m)^2}\right\} \quad \ldots\ldots\ldots\ldots\ldots(22).$$

In the present case we find

$$2t = 9{\cdot}75, \text{ and } \theta \text{ is } 60^\circ,$$

whence $$\bar{y} = 48{\cdot}8 \text{ feet.}$$

In the pier n is taken as 3, so that e, the top width, is 13 feet. By Equation (21), b, the length of a pier, works out to about 170 feet. It will be found that a length of 120 feet only is sufficient to ensure no tension if the weight of the arches is taken into consideration, but the reduction to this length gives rise to excessive compressive stress near the outer toe of the pier, so that a length of 150 feet has been adopted.

Taking b as 150, the weight of the pier is by Equation (12) found to be 10,150 tons, and by the Table in para. 21 the distance of the centre of gravity is $\cdot 3b$, or 45 feet from the upstream face of the pier.

All the dimensions and positions of the centres of gravity are now determined, and are shown on *Plate* I. Combining the weights of the pier and two half-arches, the resultant weight is 17,130 tons, and acts as shown in the Plate.

The total water pressure on the whole span is

$$\frac{1}{2} \cdot \frac{62{\cdot}4 \times (100)^2 \times 125}{2240} = 17440 \text{ tons,}$$

acting at one-third the height. The resultant R cuts the base at 96 feet from the outer toe.

It now remains to consider the maximum compressive stress set up in the pier. We have to consider a force R acting, as in the diagrams, on an area ABCDEFGHK. This area may, for purposes of calculation, be replaced by the area KLFG, with a margin on the side of safety, as the latter is less than the former.

To obtain the distribution and intensity of pressure on the area KLFG it will be convenient to consider the general problem in the first instance for figures of this shape.

26. Consider such an area ABCD (*Fig.* 4, *Plate* VI.), and take axes as shown. The intensity of normal stress will vary from a maximum Y on the edge AB to a minimum Z on the edge CD, as shown diagrammatically in *Fig.* 7. Thus there will be a series of parallel forces varying from Y to Z in intensity, and the resultant of these will be N, the normal component of the whole resultant force R acting on the whole area. Let N act at distance d from O, and let the length of the figure be l.

Let $$AB = e, \text{ and } CD = v.$$

Consider a strip of width dx. The normal forces acting on it are

$$\left\{e + (v - e)\frac{x}{l}\right\} \left\{Y - (Y - Z)\frac{x}{l}\right\} dx.$$

Therefore

$$N=\int_l^o \left\{e+(v-e)\frac{x}{l}\right\}\left\{Y-(Y-Z)\frac{x}{l}\right\}dx,$$

and by the general formula for centre of gravity

$$d=\frac{\int_l^o \left\{e+(v-e)\frac{x}{l}\right\}\left\{Y-(Y-Z)\frac{x}{l}\right\}xdx}{\int_l^o \left\{e+(v-e)\frac{x}{l}\right\}\left\{Y-(Y-Z)\frac{x}{l}\right\}dx}.$$

Solving these two equations, and writing $v=ne$, we obtain, after simplification and reduction,

$$Y=\frac{6N}{l^2e}\left\{\frac{l\,(3n+1)-2d\,(2n+1)}{n^2+4n+1}\right\}\text{ ....(23).}$$

$$Z=\frac{6N}{l^2e}\left\{\frac{2d\,(2n^2+5n+2)-l\,(2n^2+3n+1)}{(n^2+4n+1)\,(2n-1)}\right\}\text{.........(24).}$$

27. Applying Equation (23) to the case under consideration, we have

N=Total weight of pier and arch
$=6980+10150=17130,$
l=Dist. from FG to KL=188,
$e=13,$
$d=96,$
$n=\frac{KL}{FG}=3{\cdot}7,$

whence $Y=5{\cdot}1$ tons per sq. ft.

This is the maximum normal pressure at the outer toe.

If α be the angle that the resultant R makes with the vertical, then, by M. Bouvier's theorem, the actual maximum intensity of stress in the masonry is $Y\sec^2\alpha$. In this case α is very nearly 45°, so that the actual maximum stress becomes $5{\cdot}1\times\sec^2 45°=10{\cdot}2$ tons per square foot.

It is, however, somewhat doubtful how far M. Bouvier's theorem may be accepted in such a case as this, when α is comparatively large. It will be seen that the effect is to make the actual maximum intensity of stress double the normal intensity. How far this will actually be borne out in practice must be a matter of opinion, but it seems tolerably certain that the maximum stress of 10·2 tons, as found above, must err on the side of safety.

If we take Rankine's limit, as modified by General Wray, the safe limit of normal stress is given by

$$\frac{20000}{2240} \times \frac{1}{2} (1 + \cos \theta).$$

Where θ is the angle the outer face of the dam makes with the vertical, in this case 54°. Adopting this view, the safe limit of normal stress works out to 7 tons per square foot, so that with the maximum normal stress of 5·1 tons found above, there is again a large margin of safety.

28. The angle of repose of masonry on mortar may be taken as 35°, so that as α exceeds this, the pier would not be safe against sliding if the adhesion of the mortar be neglected and the masonry be built in a series of horizontal joints. But if the masonry of the pier be carried up in courses inclined at 15° to 20° to the horizontal, and care be taken to introduce vertical bonding stones, there will not be the slightest risk of failure from sliding. It is impossible to suppose that the whole pier could be sheared through. Precaution would have to be taken to prevent sliding on the base, but there will be no difficulty in doing this by benching the foundation.

29. There is a slight error introduced by assuming the water pressure to act horizontally, instead of at right angles to the inclined face of the arch ring, but this will not sensibly affect the result, and the error is on the side of safety.

In considering the stresses on the arch ring, the weight of the arch itself has been neglected. As a matter of fact, the actual stress on a small cube of the arch will be a combined stress compounded of the compressive stress due to arch action and the compressive stress due to the weight of the masonry.

Now at the bottom of the arch the stress due to the weight of the masonry is 57 tons on a base of 18·2 feet, or 3·2 tons per square foot. Compounding this vertical stress with the horizontal stress of 12 tons per square foot, the resultant works out as 12·41. The increase of stress is therefore only 0·41 tons, and is practically negligible. In very high arched dams, however, it might work out to a higher figure.

30. On the whole it is claimed that this design for a 100-foot arched dam is perfectly safe against all stresses, and that it satisfies all the conditions of stability.

31. In *Plate* II. is given a design for another 100-foot dam, in which the maximum stress in the arch is 9 tons per square foot only and the maximum stress at the outer toe of the pier 10·2 tons, the same as in the design in *Plate* I. The masonry in the arch ring is considerably thicker, but the quantity of masonry per foot-run is very little increased, in fact only from 2,312 to 2,368 cubic feet, the reason being that the extra weight of the arch throws the centre of gravity of the whole structure further upstream, and enables the length of

the pier to be reduced. On the whole, the design in *Plate* II. is to be preferred, as there will be less tendency to leakage through the thicker arch ring, and the stress is kept lower without any noticeable increase in cost.

In the design in *Plate* II. the length of the base of the dam is 120 feet and the maximum stress 10·2 tons. It is found that if the base be increased in length to 140 feet, this stress is reduced to 7·8 tons per square foot. With this design, the quantity of masonry per foot-run becomes 2,551 cubic feet.

32. *Plate* III. shows a design for an arched dam 150 feet high, with stress of 12 tons in the arch and 9·5 at the toe of the pier.

Plate IV. gives a design for a 60-foot dam. The stress is 9 tons in the arches and the maximum stress at the toe of the pier 6·7 tons.

In calculating the toe stresses for the designs in *Plates* I. to IV. the actual area of the base of the dam has been replaced by the trapezoidal figure shown in dotted lines, similar to KLFG in *Plate* I. This is on the side of safety, as the area of the trapezoid is always less than the actual area of the base of the dam.

33. The details of all these dams are summarized in the Table below :—

Height of Dam in Feet.	Maximum Stress in Arches in Tons per Square Foot.	Maximum Stress in Toe of Piers.	Maximum Stress in Wegman's Design for Gravity Dam.	Mean Radius of Arch in Feet.	Length of Pier in Feet.	Cubic Feet of Masonry per Foot-Run.	Saving Per Cent. on Wegman's Gravity Dam.
60	9	6·7	4	45·7	90	743	39
100	9	10·2		65	120	2368	29
—	9	7·8	6·4	65	140	2551	23
—	12	10·2		58·8	150	2312	30
150	12	9·5	7·5* and	60	224	6400	18
—	12	8·1	8·9	—	240	6600	15

* The maximum stress reservoir full is 7·5, reservoir empty 8·9, tons per square foot.

In the above a few details taken from *Wegman's Practical Profiles* are given for the sake of comparison with the most up-to-date designs for the ordinary straight gravity dams. It will be seen that the saving in the quantity of masonry varies from 15 per cent. for a 150-foot dam up to 39 per cent. for a 60-foot dam, without any more dangerous stresses being set up than in the corresponding gravity dams.

But the rate per cubic foot of masonry will probably be higher for an arched dam, as there will be considerably more face work, and not the same opportunities for building the work of large boulders embedded in concrete, as is so often done in large gravity dam construction. Still, this method of construction could be adopted for the piers, at any rate for the higher dams, and the arches would be built of random rubble, which is not an expensive form of masonry. Well-consolidated concrete would form an admirable material for the arch rings.

There would be a considerable saving in the cost of foundations in favour of the arched dam for two reasons :—

(1). The area of the base is less than in the case of the corresponding gravity dam.

(2). It will often be possible to so select the site that the piers will be founded on higher ground, leaving the deeper portions to be spanned by the arches. Where this is possible there will be a further saving in masonry also.

Taking all these circumstances into consideration, it does not seem unreasonable to assume that the saving in actual cost in favour of the arched dam will amount to from one-half to two-thirds the percentage shown in the above Table, and under favourable conditions it might be even higher.

In the case of the arched dam at Alwar, which was constructed in 1905 on these principles, to impound 45 feet of water, the actual saving in cost of construction amounted to 30 per cent.

34. Some of the objections to arched dams may now be considered.

(1). Before the arch action can come into play, a certain amount of deflection must theoretically occur, and this would perhaps tend to produce horizontal cracks, especially near the foundation of the arch, which would be much more rigid than the deflecting arch above. The answer to this objection seems to be that this defect has not been noticeable in actual practice, and with the small spans here advocated the deflection would be much less than in the case of existing arched dams, with radii of from 200 to 400 feet. Also a horizontal crack in the arch would not be dangerous, or tend to increase, as would be the case in an ordinary gravity dam.

(2). It has been urged that arched dams would tend to move under the changing pressures due to the drawing out or refilling of the reservoirs, and might thus become weakened, or even ruptured, in time. But dams of the ordinary type are also liable to changes of pressure from the same cause (though perhaps not to the same extent), but they do not give trouble on this account. The Meer Allum dam has stood for a hundred years and is not yet ruptured. The joints of the masonry of the Bear Valley dam are certainly said to have opened out somewhat, but the variations in stress in this case are about three times what they would be in the case of the designs in this paper.

(3). The arch rings might perhaps leak by percolation of water through the comparatively thin masonry wall. This could be prevented, if at all serious, by rendering the inner face with some impervious plaster.

35. On the other hand, the advantages claimed for the system here advocated are :—

(1). A saving of 10 to 30 per cent. in cost of construction.
(2). Better adaptation to changes of temperature.
(3). Prevention of formation of vertical cracks, which, if formed, would tend to be at once closed.
(4). Less risk of failure from horizontal cracks.

36. On the whole, it would seem that the method of construction here described is applicable with marked economy to all sites where an ordinary masonry dam would be suitable, provided the height of the dam does not exceed 150 or 160 feet. Also that there is sufficient practical experience to go upon to warrant the construction of such arched dams with every prospect of success.

APPENDIX.

DESCRIPTION OF THE AGAR DAM IN RAJPUTANA.

1. This dam was designed by the author while he was State Engineer in the Alwar State of Rajputana. The foundations were begun in March, 1905, but after seeing the foundations laid the author was transferred, and for three months or more the work was carried on by a native contractor and a native upper subordinate, without any supervision whatever by an Engineer, either European or Indian. All who have had any experience of Indian native contractors will recognize how extremely risky it was to leave an experimental work of this nature in such hands, and it is something of a marvel that the work has been as successful as it has. While it is to be regretted for many reasons that the work was not more carefully supervised, yet it is surely a point in favour of the principle of the arched dam that this work is standing successfully.

2. The site of the work is at a gap in a low range of limestone hills through which a small nullah flows. The catchment area above the site is 9·1 square miles. The gap is about 220 feet wide at the ground level and 370 feet wide at level of the top of the dam. The top of the dam is at R.L. 110, the level of the ground in the gap varying from 59 to 64, and the high flood level is 105, so that the maximum depth of water against the dam is 46 feet. The dam is founded on a bed of sound limestone throughout, at R.L. 42 to 50 in the gap.

The work consists of five arches and four piers. The two end piers are founded on the hill sides at levels 60 and 67 respectively. By this arrangement it was only necessary to provide two piers founded at about R.L. 44 in the river bed. A plan and section of a pier and arch is given in *Plate* V. The calculations were made for a dam 60 feet high with 55 feet head of water against it. Although the extreme height of the dam is 68 feet, with a head of 63 feet of water over the lowest point of the foundations, it was considered that it was sufficient to calculate for a maximum head of 55 feet, because the *average* depth of the foundations in the nullah bed corresponded to a dam about 60 feet high, and also because the soil in the river bed overlying the rock consisted of a mixture of clay and boulders more or less impervious to water, so that the actual pressure probably does not much exceed that due to a head of from 50 to 55 feet of water. Also, the dam was required to hold up water for four to five months only in the year, viz., from September to February, during the irrigation season, and the work had to be constructed with the utmost possible economy in order that the return from water rates might offer a reasonable percentage on the cost of construction.

3. Calculations have been so fully gone into in the first part of this Paper that it is unnecessary to give the calculations for the Agar dam here. They were worked out exactly as described above for the 100-foot dam in *Plate* I.

The maximum stress in the arches was taken at 9 tons per square foot, and the width of the pier was given by Equation (17), but slightly increased from 14·2 to 16 feet. The central angle of the arch is 135°, but it is recommended that a standard angle of 120° be adopted in future designs, as being generally about the most economical and convenient to adopt. The thickness of the arch at various depths was calculated from Equation (20).

The maximum *normal* stress Y at the toe of the pier works out to 4·4 tons per square foot, according to the methods described above. As the angle between the resultant and the vertical is $52\frac{1}{2}°$, $Y \sec \alpha = 7·2$, and $Y \sec^2 \alpha = 12$ tons per square foot. This was considered a permissible stress, as the stone and mortar were both particularly good, and the foundations quite sound. Also it is to be remembered that the bottom 10 or 15 feet of the arches are buried in compact clay and boulders, which must act almost as a centering to the arch, and relieve the stress considerably, so that in all probability the actual stresses developed will not be so high as calculated above.

The lines of resistance reservoir full and reservoir empty were worked out by considering 10-foot sections, as for an ordinary masonry dam. These lines are shown in *Plate* V. As the base of the equivalent trapezoid is 24 feet and top width of pier is 8, $n=3$ (*vide* para. 12), and the line of resistance reservoir full must lie within ·4 of the base from the downstream toe. This condition is satisfied (*vide* AC, DE in the Plate).

4. The foundations were laid in March, 1905, on a perfectly sound bed of hard limestone. All loose portions and cracked pieces of rock were removed, and the masonry built directly on the rock bed. The masonry was built of random limestone rubble laid in pure kankar lime mortar. The latter was of excellent quality. Great care was taken to ensure vertical as well as horizontal bond, and to prevent any empty spaces being left between the stones through which water might percolate. The work was carried up nearly to ground level before the rainy season of 1905, and resumed and completed during the winter and spring of 1906. During the rains of 1906 the reservoir filled up to R.L. 94, or 11 feet below the high flood level. I have not had an opportunity of personally inspecting the work since its completion, but I am told that there is no sign of weakness anywhere, though there is a good deal of percolation through the comparatively thin arch rings. As mentioned above, the work was left entirely without expert supervision for several months, so the percolation is not surprising.

5. The cost of construction of the work was remarkably low, the total being only Rs.40,550. It contains 248,000 cubic feet of masonry, which was built at Rs.12 per 100 cubic feet. An ordinary gravity dam of Wegman's section would have contained 396,000 cubic feet of masonry, so that the saving in the quantity of masonry amounts to over 37 per cent. Supposing that the masonry for the gravity dam could have been built at a cheaper rate, viz., Rs.11 per hundred cubic feet, the saving in cost effected by substituting an arched dam for a gravity dam amounts to just about 30 per cent. This takes into account the saving in the cost of the foundations, which was very considerable.

6. The two illustrations accompanying this paper will give a general idea of the appearance of the work. The sluices were placed in the centre of the second arch in a well built out from the upper face of the arch.

PLATE I.

100 FEET ARCHED DAM

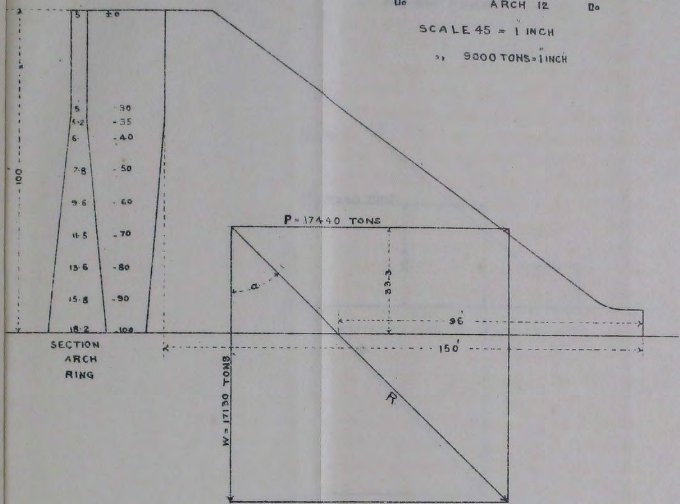
MAXIMUM STRESS IN PIERS 10 TONS PER SQ. FT.

Do ARCH 12 Do

SCALE 45' = 1 INCH

" 9000 TONS = 1 INCH

SECTION THROUGH PIER



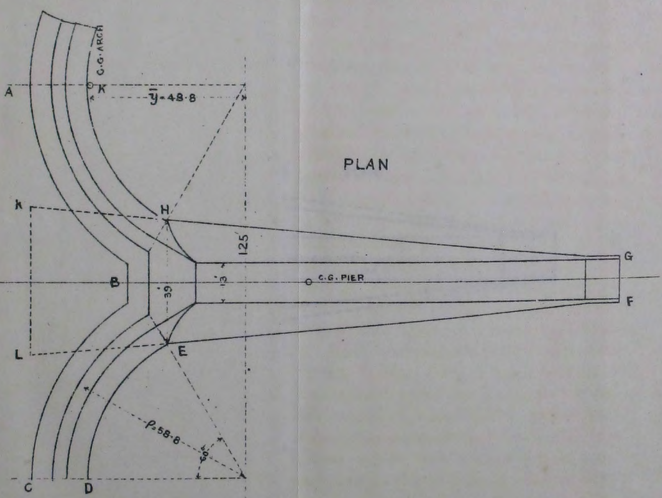


PLATE II

100 FEET ARCHED DAM

MAXIMUM STRESS IN PIERS 10 TONS PER SQ FEET
DO — ARCHES 9 — DO
SCALE 46 FT = 1 INCH
" 9200 TONS = 1 INCH

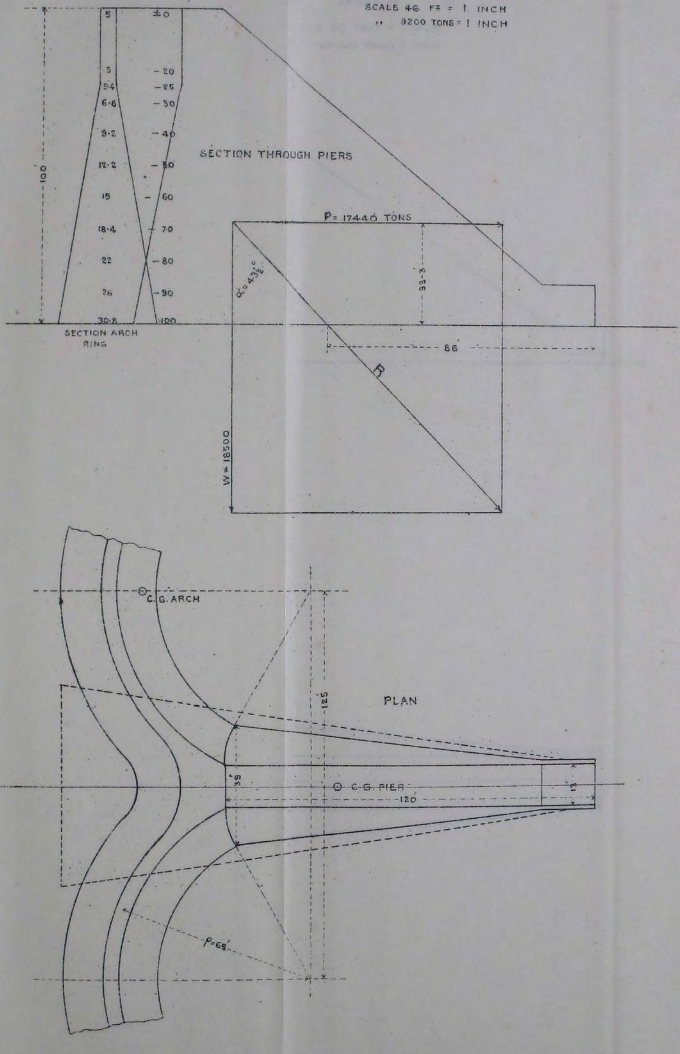
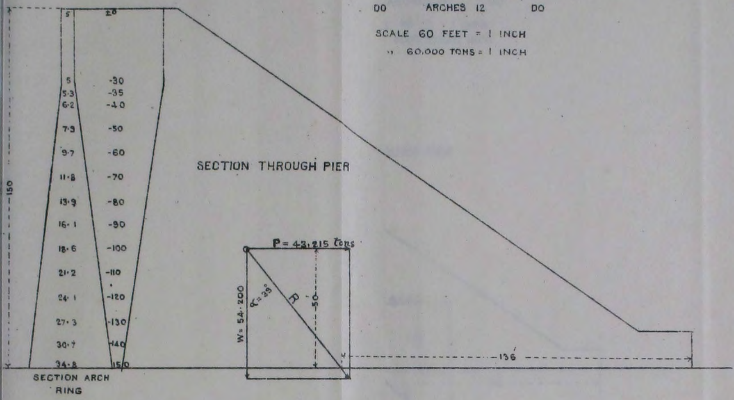


PLATE III.

150 FEET ARCHED DAM

MAXIMUM STRESS IN PIERS 9·5 TONS PER SQ FT
DO ARCHES 12 DO

SCALE 60 FEET = 1 INCH
" 60,000 TONS = 1 INCH



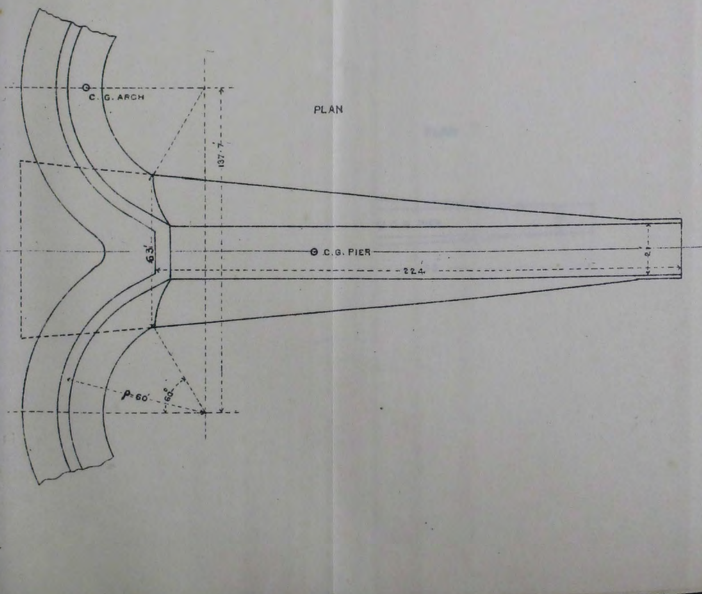


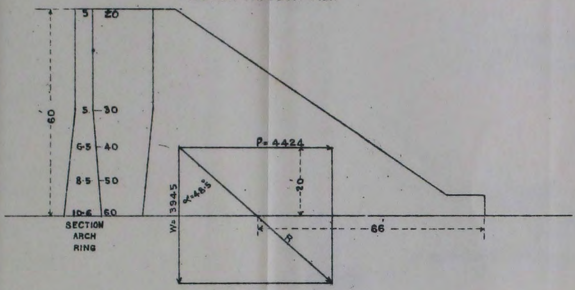
PLATE IV

60 FEET ARCHED DAM

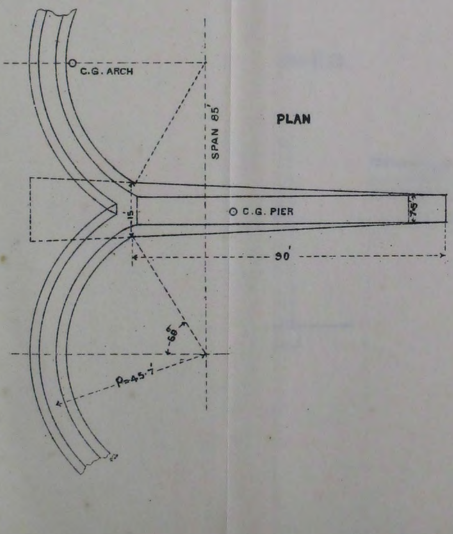
MAXIMUM STRESS IN PIERS 6·7 TONS PER SQ FT
DO ARCHES 9 DO

SCALE 40 FT = 1 INCH
" 4000 TONS = 1 INCH

SECTION THROUGH PIER



PLAN



MEER ALLUM DAM—HYDERABAD.

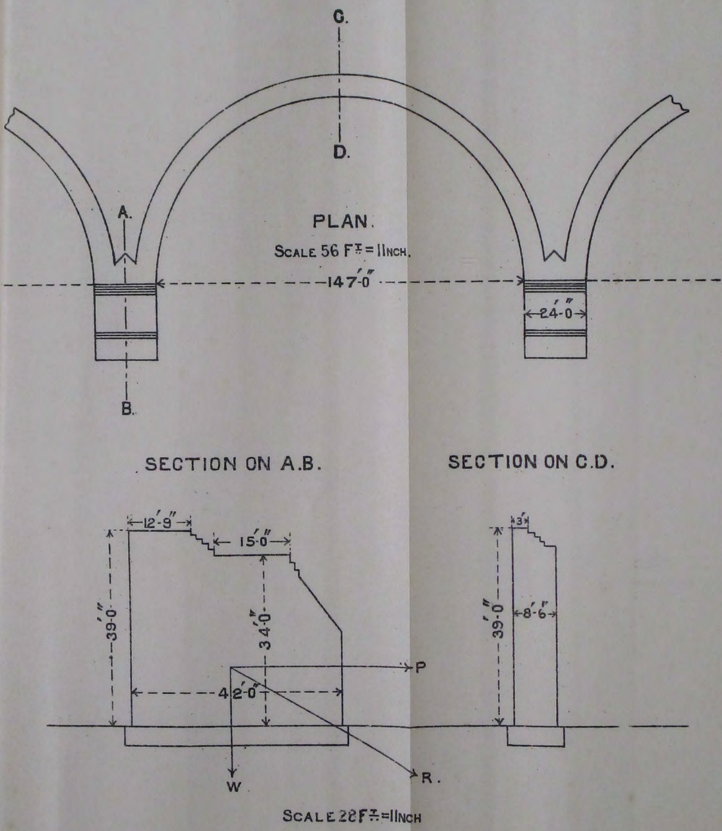
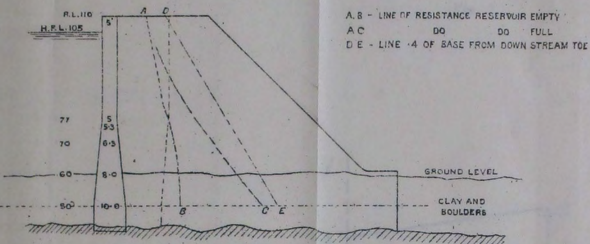


PLATE V.

ARCHED DAM IN THE ALWAR STATE

SCALE 45 FEET TO 1 INCH



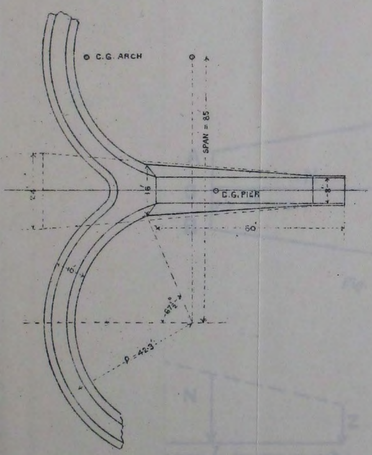


PLATE VI.

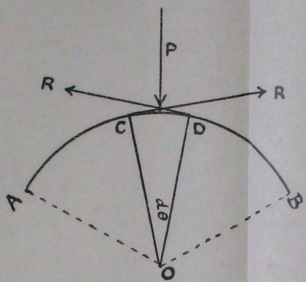


Fig. 1.

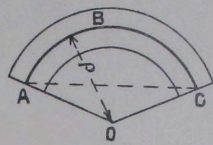


Fig. 2.

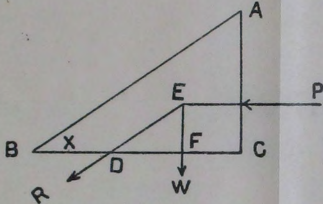


Fig. 3.

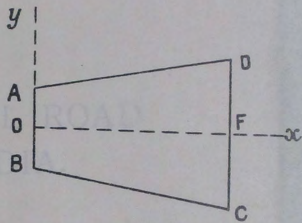


Fig. 4.

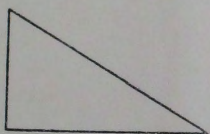


Fig. 5.

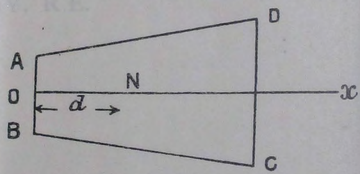


Fig. 6.

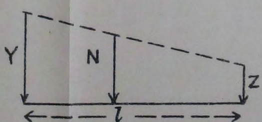


Fig. 7.

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REPORT ON MECHANICAL ROAD TRANSPORT FOR INDIA.

BY

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REPORT ON MECHANICAL ROAD TRANSPORT FOR INDIA.

THE following paper is not intended in any way as an exhaustive report on the subject of mechanical transport. It was originally written with the object of exciting some interest on the part of the railway officials in India in mechanical road transport, and is the result of considerable study, extending over a period of two years, of current practice in England. The facts and figures contained in it are derived from interviews and correspondence with manufacturers and visits to their works, War Office records, interviews with officials of the Army Supply and Transport, Mechanical Transport Branch, judges' reports, and personal observations on the 1907 Royal Automobile Club's commercial vehicle trials, current literature, etc.

The main object is therefore to give an idea of the possibilities of mechanical road transport and commercial motor vehicles, with trustworthy figures of running expenses, to enable anyone having to do with transport matters to frame for himself an approximate estimate of cost under the conditions prevailing in India.

At the same time it is a subject on which, so far as my enquiries go, railway officials and the public in India are totally ignorant, and it is difficult to decide what detail is unnecessary.

Possibility of Mechanical Road Transport in India.

The possibilities of success of mechanical road transport in India is occasionally written about in English technical periodicals, but, so far as I have seen, by persons without local knowledge of the conditions of the country, habits of the people, or the requirements of trade.

In discussing the question with Indian officials a very common objection raised is "Where would one get roads in India which would take motor traffic?" In many cases roads exist which would take it. In others it may be found on examination that it would pay to improve the roads so that they would do so. This can only be decided by estimate in each case.

Effect on Roads.

As regards the cost of road maintenance under commercial motor traffic, it is by no means certain that, on roads properly maintained, it is greater than under horse or bullock-drawn carts, provided the motors are properly driven.

A bullock cart carries 20 maunds, or 1,600 lbs., on two wheels. The cart and wheels weigh not less than 8 maunds, or 640 lbs. Total, 1 ton. Its tyres are usually about $1\frac{3}{4}''$ broad, and the tread is not flat, but roughly semi-elliptical in section. This gives $\frac{1}{2}$ ton on $1\frac{3}{4}''$ tyre even if the tyre were rectangular in section. The bullocks track practically with the wheels, and are iron shod, with pointed shoes. Bullock cart wheels are about $4'$ in diameter, and the cart has no springs.

It is impossible to make a bullock cart travel otherwise than in the tracks of those preceding it, thus bringing all wear on two narrow strips of the road surface. It travels 2 to $2\frac{1}{2}$ miles an hour. Compared with this, a small steam tractor by law has $2''$ tyre width on each driving wheel per ton of engine (not per ton of weight on driving wheels).

A 5-ton tractor would have about 4 tons on the driving wheels, which would be $12''$ wide, giving $\frac{1}{6}$ of ton per inch of width against $\frac{2}{7}$ ton per inch in the case of a bullock cart. Its driving wheels are $4\frac{1}{2}'$ to $5'$ in diameter. It is effectively spring-mounted on both axles. From its method of drive however it tends to push the road surface behind it, and it travels twice as fast as a bullock cart.

It is impossible to calculate which method of transport causes most wear on a road, but taking the above into consideration it would not be surprising if it were found that the light tractor is the less destructive.

A bad driver will destroy road surfaces where a good one will not damage them. Thus if a heavy engine with iron tyres is driven beyond a certain pace it has a hammering effect on the bottom of every depression in the road surface. If continuously driven in the same track it will wear a rut in the surface, whereas by varying the track in different journeys the wear is distributed over the whole road. Wet patches are softer than dry. A good driver will avoid them as far as possible.

In the case of fast motors with rubber tyres the effect of too great a pace is to suck the binding material from the joints of the metalling. This takes place more especially when the road is wet. A good driver will therefore avoid places in the road where water is standing in puddles, and will keep to time by travelling at as uniform a pace as possible.

On the other hand, in the case of road repairs, a stitch in time saves 9 in the road and 19 in the motor. A bad patch of road very quickly becomes worse under motor traffic, and causes undue strains on the machinery, resulting in heavy repairs.

Faulty drainage means a soft wet surface wearing quickly and causing side slip. Excessive camber largely destroys the advantage of wide tyres and tends to concentrate the load on strips of road narrower than the wheels, to the detriment of both road and wheels.

Weak foundations may largely be counteracted by thorough drainage and by making the surface as waterproof as possible.

Thus it is that successful running of road motors largely depends on the way roads are maintained, and the cost of road maintenance on the way motors are controlled.

Motors can be controlled by law, but road repairs cannot. In a country like England public opinion largely keeps a road department up to the mark. In India it would be advisable for the road repairs to be done by the motor service running on it, the service being of course subsidized to the extent of what the road repairs ordinarily cost Government to do them departmentally.

Possible Causes of Failure of Road Motors.

Road motor services have been tried in India in several places, mostly with indifferent success. It is foolish to quote such failures as a proof that mechanical road transport is unsuited to the country without studying the causes of such failure. Yet this is frequently done by persons who ought to know better. I have often heard it said "You know the motor buses in London are in a bad way, practically a failure. If they cannot be worked at home, commercial motors will never do in India." Such reasoning is absurd. The failure of a motor bus company does not necessarily imply that motor buses are failures, still less that all motor transport is so.

A company may be ruined by many factors besides the inefficiency of the vehicles which it uses for its work, and a mechanical transport service may fail among other things from over-capitalization, incapable management, incapable drivers and mechanics, unsuitable vehicles, competition such as reduces freight charges to a non-paying rate, excessive speed on bad surfaces, overloading, slack road repairs, excessive taxation, or obstructive government regulations and interference, etc.

Again I have heard the objection raised that as bullock carts can compete for freight with the railways in many places in India, there is no likelihood of any form of road motor being run profitably.

It may be true that bullock carts do take freight in some places which might be carried by rail. I once, out of curiosity, traced through the books of a certain Indian railway a number of consignments booked on routes off the main line in such directions that they passed through several junctions and engine-changing stations. The rate of travel from booking to destination station worked out to between ·5 and 1·5 miles an hour in most cases. A bullock cart can travel 2·5 miles an hour.

Conditions of Traffic, etc., likely to afford an Opening for Road-Motor Transport.

Many traffic routes such as are worked by the railways as out-agencies with bullock-cart services, particularly in the North-West, should be workable by mechanical means. At present there is no means of overland transport in India intermediate between the railways worked with all modern refinements, and bullock carts and pack animals working as they did thousands of years ago.

There are many places where traffic is insufficient in quantity to justify a line of rail, but sufficient in importance to require something quicker and more trustworthy and reliable than the bullock cart.

Also there are situations where railway extension is hampered owing to the law governing the maximum freight per ton-mile which may be charged. Given a trade route with a light traffic and high rates of bullock-cart freight several times higher than the maximum allowed by law on the railways, a branch line is possible, and could be profitably worked but for the rule governing the maximum freight charge.

Again there are cases where there is considerable and important traffic between two places for a portion of the year only, which requires better transport than the ordinary bullock or pony cart, and which almost ceases for a large portion of the year.

A railway, to serve such a route, is impossible owing to the heavy maintenance expenses being almost constant, irrespective of the quantity of traffic. In such situations there is probably room for mechanical road transport.

Advantage of Control by Railways.

A railway has many advantages over private enterprise in instituting road-motor services. It has command of mechanical engineering workshops for repairs, and trained drivers and mechanics. Administration expenses would be light compared to those of a separate company. Men with first-class technical knowledge of motors, or indeed any machinery, cannot be picked up in India easily, and a motor expert from England would not have the requisite local knowledge.

The railways connecting with such road services would benefit by extra traffic fed to the line, and would therefore consider the profit made in carrying such extra traffic over the railway as a credit to the expenses of the road services.

Thus many railways in England run passenger motors on the roads as feeders. Even if when considered as separate concerns they barely pay expenses, yet they can rightly be regarded as profitable, owing to the extra traffic on the railways due to them. Under such circumstances it is needless to say that these services could not be run by private enterprise.

Railways have facilities possessed by no other department of Government, or by the public, of being able to estimate the traffic on adjoining roads with a view to the introduction of mechanical transport. And having instituted such services, are in a position to foster trade by adjusting freight rates, until traffic assumes such proportions that extension of the railway in supercession of road traction becomes possible.

If, as is possible, it is found necessary to hand over repairs of roads, on which mechanical transport works, to the same administration as that which controls the motors, railways have facilities for cheap transport of road metal, bridging material, etc., enabling them to undertake road repairs cheaper and quicker than any independent department or private enterprise.

A railway, with more than one such service on its system, would be able to transfer motors from one to another as the exigencies of traffic required, and would need fewer spare vehicles to allow for extraordinary traffic, breakdowns, repairs, etc., than would be necessary if they were under different companies.

Accounts and book-keeping would be arranged economically, precisely as for a branch line of railway.

But perhaps the most important consideration is that the railways in India, being to all intents and purposes Government property, road motors under their administration would be available for military purposes in time of war, and would cost the military department nothing in time of peace. They would be available, fully equipped with stores, drivers, mechanics, and other staff accustomed to their working.

It has been recognized for many years in Europe that mechanical road transport is necessary to any large military movements in war, and indeed in peace time also. For this reason the War Office have instituted a special department for studying the various types of vehicles brought on the market, and from time to time institute and assist in competitions between them, offering rewards for such as are most suited to Army purposes.

They also have a system of registering motor vehicles of private owners in England, and in consideration of certain fees such owners agree to allow their vehicles for hire in peace time for manœuvres, etc., and for purchase by the War Department in time of national necessity. Such system of registration would of course be possible in India with services run by private enterprise. But the vehicles so obtained would inevitably be of more or less efficient and suitable patterns and of many different makes, involving a mass of stores and spare parts of different kinds. Moreover there would be a difficulty in obtaining the staff to work them in war time.

The requirements of motor vehicles for Army supply work and for commercial purposes are much the same, and it should not be difficult to arrange that all railways use the same makes and patterns as far as possible. In fact, especially in the North-West, it is probable that traffic routes exist off the line of railway where mechanical transport could advantageously be introduced by the railways, even at a loss, for the sake of having at hand motor vehicles fully equipped in case of military necessity. This can of course only be decided by local enquiry and estimate.

Mechanical road transport services in India should therefore be under the railway administration. They should be worked exactly as branch lines, with through booking and railway risks.

Matters to be Guarded against in Railway Management.

On the other hand, there are certain disadvantages which road-motor services are likely to suffer from if controlled by railways in India.

(*a*). Excessive control from headquarter officials without technical or local knowledge, causing delay in maintenance repairs to vehicles and loss of traffic.

(*b*). Excessive control over and delay in sanctioning petty revenue expenditure.

(*c*). Delay in payments from the railways for work done, causing enhanced rates and difficulty of obtaining labour.

(*d*). Stinting the pay of staff, with the idea of cutting down working expenses at the cost of efficiency, resulting in high maintenance of motors, big repair bills, and unreliable running.

(*e*). Officials in charge gaining experience at the cost of their engines.

(*f*). Divided responsibility owing to division of control between several departments.

The avoidance of such disabilities should not however be insuperable. A lesson from English railway experience may not be out of place. One of the largest English railways, which makes a great feature of road-motor services for passengers, has now some 30 services in various parts of the country, all controlled by a superintendent with one assistant. When first this branch of traffic was instituted the locomotive department had care of engines and engine staff, and the traffic department, of traffic arrangements and traffic staff. Such a system was inevitably found unworkable, and the whole department is now in charge of the superintendent of road motors—a locomotive engineer nominally under the traffic superintendent of the railway, with whom all traffic arrangements are discussed, and from whom he obtains any assistance he requires in traffic matters. He has absolute control over his expenditure as head of a department, and is responsible financially to the general manager only. He gets his repair work done where and when he considers necessary, doing it in his own workshops independent of the railway locomotive ones, or by outside firms, or in railway locomotive workshops, according as he thinks fit with regard to economy and efficiency. As a revenue-earning department he is given a free hand and judged by financial results.

If similar arrangements of control in India are impossible owing to the exigencies of red tape, then mechanical road transport is unworkable except by private enterprise.

This question of control is a point to which great prominence was given by a high railway official in India when discussing the possibilities of road motors with me. His opinion was that they were impracticable owing to the difficulty of control from headquarters of the railway. Control, from headquarters on the part of officials, of details which should be left to the man in charge is the thing above all others likely to ruin anything of the kind financially. Control by means of statistics of profit and loss is sufficient and presents no difficulty. It goes without saying that the working of such services requires an official in charge with an aptitude for business and technical knowledge.

It is frequently said that commercial motors would be a failure in India owing to the dust prevailing in many parts of the country, which would cause so much wear as to quickly put them out of action. This difficulty is largely exaggerated. Motors nowadays have their gears and most moving parts cased in, as a protection from dust. Effect of dust.

As regards climbing steep roads, the modern motor vehicle can go wherever a horse or bullock-drawn cart can work. Grades.

The economical driving of a road motor requires a much greater skill than that required for a locomotive running on rails. It is therefore important that, for commercial motors, the driver and mechanics should be the best possible. A really first-class driver will not only save 50% of the fuel which an average good one requires on the same engine, but also an incalculable amount in wear and tear of engine and gear. Importance of First-Class Staff.

Pay of drivers should of course be fixed on the basis of fixed pay and mileage, with bonus for saving fuel. Many firms find it a good system in the case of petrol engine drivers, to issue all fuel on payment, their mileage rates of pay being fixed to allow for this. It is dangerous to give drivers too great an incentive to economize lubricating oil, but it forms a large item of expense and requires careful watching.

Reliable statistics of costs of working are very difficult to obtain. Most users of commercial motors keep no record of work done or repairs and running expenses. Others keep rough accounts, leaving out important items of expenditure. Again, no two cases are alike. Difficulties in obtaining Statistics of Running Costs and Capacity.

Heavy continuous work with insufficient time for cleaning and overhauling means a high repair bill. Many users again employ motors for work involving much waiting for loading and unloading. Statistics from this class of user are useless, while manufacturers' records, though possibly correct, are not disinterested.

The ideal work for profitable running consists of regular daily long journeys with through loads, with the minimum of waiting for loading and unloading.

Again, manufacturers' catalogues are usually confined to pretty pictures of motors doing extraordinary feats of endurance or power, and though particulars of price and rough specifications are obtainable on application, it is not easy to obtain complete particulars of fuel and water consumption, repair costs, loads, performances on grades, weights on axles, overall dimensions, minimum turning circles, and the many details required by a prospective Colonial user before he can decide whether a certain type of motor will suit the conditions of his work.

Tyres.

Steam lorries and tractors are built with steel-tyred wheels. Tyres made of wooden blocks built on to the rims of the driving wheels are used, and are said to be successful in giving a good grip on greasy stone setts and in reducing vibration, but they are not in general use at all.

When speeds are required too high for the steam lorry or tractor, internal-combustion engined lorries are used mounted on rubber tyres.

A feature of the late commercial vehicle trials under the R.A.C. was the use of such motors for loads up to 5 tons. But the wear on the tyres is very great even in a cold country. This however is, of course, a question of the possibility of getting freight which will pay for such wear.

For light delivery work for tradesmen, for motor cabs, and other fast vehicles of about 1 ton tare weight to carry ½ ton, pneumatic tyres are used, or pneumatic on the front wheels and solid rubber on the rear ones.

It should be understood that the necessity for lower speeds on solid tyres is not due to the inability of engines to drive at fast speed with such tyres, but to the fact that no engine and gear will stand the vibration and jolting. All commercial motors should therefore be fitted with governing arrangements on the engine, fixing the maximum speed at which the driver can make his vehicle travel.

Selection of Motors.

The commercial motor has nowadays reached a state of great efficiency and trustworthiness, yet in selecting any particular make it is necessary to exercise great care in ordering the most suitable for the work expected of it.

It is, above all, important to use as few different patterns of engines and chassis as possible on any one service, or set of services. Drivers and mechanics require a certain amount of special experience for any particular make, and spare parts must always be in stock to provide for renewals and repairs being carried out with as little delay and laying up as possible. With several patterns of motor, spare parts are liable to amount to a very large sum of money.

Many transport companies in England are suffering to-day in this manner, through having had to purchase their experience of various makes in the days when the commercial motor was less standardized and when the performances of various makes were not so well known as they are now.

This matter is especially important in India, as, owing to the unavoidable delay in procuring spare parts in that country, a larger stock must be kept in hand than is the case in England.

A case in point is the English railway referred to above. Their services were commenced in the early days of road motors, and they have had to discover, by a very expensive experience of trial and error, the type and make of chassis most suited to their requirements. In consequence, their stock of spare parts amounts to many hundred pounds value, as they have to keep them for every type in use. They now purchase one make exclusively, of course fitting the chassis with various types of body according to the requirements of traffic.

To stand the vibration and strains set up in the engine, frame, and gear of a modern road motor the very best materials and workmanship, besides good design, are required, and this can only be thoroughly tested by a long period of use, under Service conditions.

The best method of selection is by taking the advice of disinterested firms or others who have had years of experience as users. This may be readily obtained in England.

The Mechanical Transport Committee of the War Office have done a very great deal of investigation into the possibilities of road motors since they first gained any importance, and the Great Western Railway have also had a large experience in certain classes of work.

It is only after maybe a year or two's work that a motor vehicle will begin to show whether it is truly economical or not. It is of course of paramount importance that only manufacturing firms of good financial standing be dealt with. For, in the event of a manufacturing works closing, it is impossible to obtain spare parts of engines of that make without great expense.

It should be borne in mind that any divergence required from the maker's standard pattern of chassis, requiring special parts or material, is expensive both in first cost and renewal.

When deciding what firms to deal with, a priced list of spare parts should be insisted on from the makers. Most firms object to doing this but it is most important, especially in India, where the delay involved in obtaining parts from the makers has to be set off against the extra cost and inferior workmanship of locally made ones. Most large firms however will supply unpriced lists of spares with code letters or words to each to facilitate orders by telegraph. First-class firms also supply spares to fit their engines accurately, without any alteration being necessary when replacing worn ones.

Motors for Goods Traffic.

For haulage of loads of goods not requiring a greater speed than an average of 5 miles per hour the cheapest form of motor is the steam lorry, tractor, or traction engine.

A lorry is a vehicle in which the engine and load are carried on the same frame. Steam lorries are also known as steam wagons.

A tractor is a light hauling engine or traction engine.

A traction engine is a heavy type of tractor.

There are a great many different makes of these motors giving entire satisfaction to users in England, and successfully competing both with the horse haulage and the railway for certain classes of work. Most well-known types are thoroughly reliable, and have been practically standardized for some years.

The steam wagon is the result of a demand for a motor which can manœuvre in small spaces with its load, either forward or backward, such as in warehouse docks or at quays.

Thus in certain conditions a lorry can be used where a tractor cannot.

As regards expense of running, the light steam tractor and the steam lorry work out to very much the same, the advantage being slightly in favour of the tractor.

Performances of Steam Lorries.

A trustworthy pattern of lorry can be obtained to carry 5 tons. Such lorry would weigh $6\frac{1}{2}$ to 7 tons unladen, but in working order, with water, fuel, and staff, it would cost about the same as a small tractor.

The following record of an experiment carried out under careful supervision will give an idea of the capabilities of such motors and a basis for estimating cost of transport by their means :—

	Tons.	Cwts.
Weight on front wheels of lorry when unloaded but fully equipped	2	$2\frac{3}{4}$
Ditto, rear wheels	4	$17\frac{1}{4}$
Total	7	0
Weight on front wheels of lorry when loaded	1	$19\frac{1}{4}$
Ditto, rear wheels	8	2
Total	10	$1\frac{1}{4}$
Trailer, unloaded weight	1	$1\frac{1}{2}$
,, loaded ,, ...	3	$1\frac{1}{2}$
The run on English roads, in winter weather, was	257·25 miles.	
Ton-miles carried (useful load)	1286·25 ,,	
Water consumption { Total	1909 galls.	
Water consumption { Per ton-mile of useful load ...	1·48 ,,	
Coal consumption { Total	3108 lbs.	
Coal consumption { Per ton-mile of useful load ...	2·49 ,,	
Water-tank capacity	145 galls.	
Radius of travel on water tank with 5-ton load	19·54 miles.	
Minimum turning circle diameter	36′	
Speed up 878′ of 1 in 8·4	2·2 miles per hour.	

Descending same slope stopped in 1·5 yards from 4·2 miles per hour from time of ordering stop.

Extreme width of lorry	7′
Platform area 6′ × 9′	54 sq. ft.
Sides and ends, removable height	2′
Height of lorry platform loaded	4′
Height of driving gear from ground ...	10″
Diameter of driving wheel	4½′
Width of tyres { Front	5″
Width of tyres { Rear	9″

In the late Royal Automobile Club commercial vehicles trials, out of four steam lorries of different makes, carrying 5 tons load each, the coal consumption varied between 2·24 and 3·65 lbs. per mile average over a distance of 688 miles, which was covered in 22 days. The involuntary stops for other purposes than picking up water were practically nothing. The speed was limited to 5 miles an hour. The vehicles were driven by specially skilled drivers with best English coal. Good native drivers would probably use 100% more coal of the same quality.

The following is an example of a very good performance of a steam lorry, which had been in use for some 16 months, in the hands of an exceptionally good driver.

The lorry with trailer, both empty, was driven out 12 miles, picked up a load of 7 tons, and returned the same day. The road contained numerous gradients, and the surface was mostly large stone setts, in places partly covered with snow. The weight of the steam wagon, with 277 lbs. of coal in bunker and water tank full, was 6 tons 13½ cwts. 62½ lbs. of coal were used on the outward journey, which took 2½ hours. The load returning was 4 tons 14 cwts. on the wagon and 2 tons 6 cwts. 38 lbs. on the trailer—total, 7 tons 38 lbs. The coal used on the return journey was 131 lbs., which lasted 3 hours 3 mins. Allowing 28 lbs. coal for raising steam originally, the total consumption amounted to 221½ lbs. Coal per mile, with wagon and trailer empty, but carrying loading tackle and three men, was therefore 5·2 lbs. Coal per mile loaded with 7 tons useful load was 10·9 lbs. This gives coal per ton-mile useful load 1·55 lbs. The lubricating oil used was 1 quart. The coal was Nixon's Navigation.

The following is the maker's description and estimate of a good pattern of steam lorry built for Colonial work :—

A Maker's Specification for a Steam Lorry.

Capabilities.—It is capable of carrying 5 tons and drawing 2 tons behind on a trailer at 5 or 6 miles an hour, and up gradients 1 in 7 on good roads ; the platform is 11′ × 6½′, the sides 1½′ deep.

Boiler is built on the horizontal locomotive type, and made throughout of Siemens' mild steel, hydraulically tested to 350 lbs. for a safe working pressure of 200 lbs.; the fire-box is made specially large for easy steaming with coal, coke, or wood fuel; the total heating surface in fire-box and tubes is 90 square feet.

Engine is of the compound type; cylinders (steam-jacketed) are H.P. $4\frac{1}{8}''$, L.P. $6\frac{1}{2}'' \times 7''$ stroke. It is fitted with patent high-pressure gear, whereby the engine can be instantly converted into a double high-pressure one, each cylinder receiving steam separately from the boiler and exhausting independently into the funnel; this increases the power of the engine about double for ascending very steep inclines, also makes it much handier for working in awkward places, as no reversing is required when starting.

Gearing.—Two speeds are arranged—3 and 6 miles an hour—and are interchangeable by one lever from the footplate. The driving is done by steel-cut gearing from the crankshaft (which is perfectly balanced) to phosphor bronze gearing on a fixed stud shaft, and from there by a strong Renold roller chain to compensating gear on main axle.

Wheels.—The road driving-wheels are $4'$ diameter by $12''$ on face; the forewheels are $3'$ diameter by $6''$ on face.

Brake.—An efficient band brake is fitted to work on a large hub, which is keyed on the main axle.

Water Tank and Fuel Bunker.—The tank holds 170 gallons, and is sufficient to take the full load 15 to 20 miles on good roads. The fuel bunker will hold sufficient for a 40-mile run.

Feed Water to Boiler.—One injector and one pump is fitted. Water lifter is fitted with $24'$ of $1\frac{1}{2}''$ suction hose pipe.

Bearings.—All bearings are of phosphor bronze, and the engine is automatically lubricated throughout.

Levers.—All starting, steering, reversing, and gear levers are within easy reach of the driver.

Outfit consists of full set spanners, oil cans, three lamps, tun-dish, spare fusible plug, gland, packing, screwjack and bar, frost studs, hand hammer, cold chisel, etc., complete.

Guarantee.—The makers undertake to make good any part of the wagon which may fail or break within three months from date of delivery, provided that such breakage has not been caused by improper usage, neglect, or accident.

Price.—£550 cash against bills of lading F.O.B. any English port plus £10 for packing for export.

Delivery in nine weeks.

The Steam Tractor's Advantages over the Steam Lorry.

For work in India, outside the larger towns, the steam tractor has many advantages over the steam lorry.

A tractor can be fitted with larger driving wheels, giving smoother running on rough roads, with consequent greater haulage power and less wear on machine and road. A small difference in this respect makes a very large one in wear and tear.

A tractor also has the advantage in being fitted with a winding drum and wire rope, enabling it to extricate itself or its load from boggy or greasy places, and to wind its load after it up steep grades or over bridges too weak to stand it when coupled to its load. It is usually fitted with a locking device for the differential gear, to help the engine when one driving wheel is on a greasy or soft patch. This should be worked from the footplate. It can be fitted with a crane for moving heavy loads, and for loading and unloading its trailer. It is suitable for use as a stationary engine for driving machinery, electric light, etc. It can be temporarily converted to a road roller when required to repair its own road. It does not require to wait under steam while loading and unloading is in progress. If disabled on the road its load can be taken over by another tractor without delay or difficulty.

Light *versus* Heavy Tractors.

The relative advantages of light or heavy tractors depends very much on the nature of the roads over which they have to operate.

When the roads are first-class, and bridges of ample strength, a heavy engine is cheaper and more satisfactory than a light one. Across soft country or on soft roads with weak bridges the light engine is necessary.

Light engines require more skill in firing and in keeping them in working order than heavy ones, as dimensions of all parts are kept as low as possible. At the same time a light engine requires less skill in driving over soft or badly drained roads than a heavy one.

Generally speaking, a heavy engine uses less fuel and water per ton mile on hard roads and good country, while on soft roads the lighter engine may have a slight advantage. A larger amount of fuel and water in proportion to expenditure per mile can be carried on the large engine, thus giving it the advantage of a greater cruising radius.

With heavy engines it is probable that there would be more light running than with light ones, owing to full loads not being always available. The laying up of a large engine for repairs is equivalent, as regards lock-up of capital, to laying up two small ones.

It is found in practice that two tractors coupled can, under certain conditions, pull more than double what either of them could move separately. This is due to the fact that, when coupled both the engines seldom get on a greasy patch of road at the same time, or meet inequalities of surface at the same moment. Therefore, when possible, it is best to run engines in pairs, each with its load behind it, so that in difficult places, or in case of breakdown, they can assist each other. This should be taken into consideration when deciding the size of tractor to use, for the traffic may be insufficient for the large engines working continuously together. Steam lorries and tractors as made for work in England require little or no special fittings for work in India. Such as are required are provided as standard by manufacturers for Colonial work. Such are large fire-boxes for inferior coal, extra-sized water tanks, larger diameter, and broader tyred wheels.

Some Points in Design and Fitting of Tractors.

Most makers make two or three classes of tractors varying in quality to suit the pockets of users. The chief points of such variation are in quality of material, workmanship, size of wheels, spring mounting, number of cylinders, and dust casing for gear.

Driving Wheels.—The tractive power of an engine depends among other things on the adhesion between the driving wheels and the ground. This depends on the weight, diameter of wheels, and breadth of tyre. Any reduction of weight is advisable that is possible without sacrifice of adhesion.

Width of tyre beyond a certain amount is objectionable as causing great strains on the wheels on rough surfaces, and is moreover useless owing to road camber. The larger the diameter of the driving wheels, the greater the clearance between the engine and the ground, and this is obviously desirable in rough country. The larger the driving wheels, the less are inequalities in the road surface felt, and the less likely is an engine to break through bad foundations, owing to the weight being distributed over a larger surface of contact with the ground. It is advisable therefore to have as large wheels as possible.

Spring Mounting.—Makers supply them both with and without springs. This is a matter of price only. Spring mounting pays. A driver cannot stand the vibration of a full day's work, travelling on the footplate of a rigidly mounted tractor. The wear and tear on the engine of such a tractor is very great, and its tractive power is less owing to the higher resistance caused by inequalities of surface of road. No diminution in weight can be effected by spring mounting, for though parts can be made somewhat lighter owing to their having to withstand less vibration and jolting, yet this is made up for in the extra weight of the springs and their attachments. So that it is advisable to have spring mounting, and that it should be thoroughly effective.

Number of Cylinders.—Steam tractors are made both single and double cylinder. The best and most economical type in common use is with two cylinders compounded, the steam being used expansively. Briefly, the advantages of such arrangements over the single cylinder, or two simple cylinders, are :—

(*a*). Economy in working.
(*b*). Greater ease in handling.
(*c*). Less tendency to priming.
(*d*). Less risk of fire to buildings, etc., through hot embers from the chimney.
(*e*). Less noise from the exhaust.

Such engines are commonly fitted also with an arrangement for admitting high-pressure steam to the low-pressure cylinder. This is a most desirable fitting, assisting the engine to start with heavy loads, to extricate itself in soft places, and on heavy grades. It should be designed so that in the event of an accident to one cylinder the engine can be worked on the other one until convenient to repair it.

Dust Casing on Gear and Motion.—Difficulties with dust in India are largely exaggerated except in particular localities.

The following objections have been raised to dust casing on tractors :—

(1). It adds to the weight of the engine.

(2). It interferes with the driver watching the motion work, and occasionally feeling it for heating. This is a matter of design however, and many casings are well designed so that they can be opened and closed without trouble.

(3). It interferes with lubrication. This can also be overcome by good design.

(4). If not carefully designed it interferes with the driver's view.

(5). It adds to the noise of the engine when it has got loosened with continuous use. This is largely a matter of original design and good maintenance.

All steam tractor and lorry specifications should be based on the one for material used in the construction of railway rolling stock, issued by the British Engineering Standards Committee.

The following Table is compiled from the most trustworthy statistics available, and may be taken as a safe estimate of cost in England. It should be possible without difficulty to work out in any particular case under Indian conditions the cost of working such engines.

Estimated Running Costs of Steam Tractors.

	Large Tractor.	Light Tractor.
Weight of tractor without fuel and water	14 tons	5 tons
Tare weight of wagons hauled ...	3 at 3 tons each =9 tons	2 tons (one)
Useful load	18 tons	5 tons
Gross weight, including fuel and water	$43\frac{1}{2}$ tons	13 tons
Maximum weight on any axle ...	10 tons	4 tons
Daily mileage	24 miles	30 miles
Average speed on road	4 m. p.h.	5 m. p.h.
Annual mileage at 260 working days	6,240 miles	7,800 miles
Annual net ton-mileage, allowing return journey empty	56,160 ton m.	19,500 ton m.
Fuel consumption per gross ton-mile	1·0 lbs.	1·5 lbs.
Ditto per mile with full load ...	43·5 lbs.	19·5 lbs.
Ditto per ton-mile of useful load ...	2·42 lbs.	3·9 lbs.
Lubricating oil per mile	·32 pints	·1 pint
Annual cost fuel	£144	£82
Ditto lubricating oil...	£10	£4

	Large Tractor.			Small Tractor.		
	£	s.	d.	£	s.	d.
Annual wages driver, £1 10s. per week ...	78	0	0	78	0	0
Annual wages steersman, £1 5s. per week	65	0	0	—	—	—
Annual wages brakesman or assistant, £1 per week	52	0	0	52	0	0
Annual cost of small stores, cotton waste, firewood, etc.	50	0	0	25	0	0
Capital outlay...	1040	0	0	600	0	0
Depreciation, 12 %	125	0	0	72	0	0
Repairs, 10 %	104	0	0	60	0	0
Housing and sundries, 3 %	31	0	0	18	0	0
Total annual cost	659	0	0	391	0	0
Allow 10 % for contingencies	66	0	0	39	0	0
Grand total	725	0	0	430	0	0
Cost per net ton-mile with load, in one direction only	0	0	3	0	0	5¼
Note.—Coal is taken at 30s. per ton. Lubricating oil at 9d. per gallon.						

The following may be taken as the latest practice :—

	Large Tractor.	Small Tractor.
Length over all	18′	14′
Width over all	7′	5½′
Wagon's length, including drawbar	20′	20′
Wagon's width over all	7′ 6″	7′ 6″
Brake horse-power	45	30
Radius of action on water tanks ...	12 miles	30 miles
Consumption of water	·8 gals. per lb. fuel	·9 gals. per lb. fuel

The consumption of fuel is for average English metalled roads and good drivers. Inferior condition of road or driver may vary the figure to any extent.

A 5-ton steam tractor can be made to turn in as small a circle as 26′ diameter with trailer. Its weight in working order would average front axle 2 tons, rear axle 4 tons. As a road roller converted it would weigh 8 to 10 tons according to make. Wheel base of tractor, 7½′. Height over all, 9½′.

The following is the War Office specification for a light tractor, and is worth noting :—

A Light Tractor Specification.

1. *General.*—A two-cylinder, compound, spring-mounted road engine, to be capable of hauling a gross load of 8 tons over average roads for at least 30 miles without stopping to fill up water tanks or coal bunkers, and up gradients of not less than 1 in 12. Registered weight not to exceed 6 tons.

2. *Speed.*—The speed on the top gear is not to exceed 5 miles per hour. The engine to be fitted with at least two speeds.

3. *Cylinders.*—The cylinders are to be fitted with suitable mechanical or displacement lubricators, drain-cocks, and glands. The barrels to be lagged and covered with planished sheet steel. A suitable arrangement is to be provided for the admission of high-pressure steam to the low-pressure cylinder.

Two test bars, each 3′ 6″ × 2″ × 1″, shall be cast on or with each cylinder. These, when placed on edge on bearings 3′ apart, and loaded with a weight of 33 cwt. upon the centre, must show a deflection of at least $\frac{3}{8}$″ before fracture.

Each cylinder, when fitted complete with its covers, shall be subjected to and shall satisfactorily withstand a hydrostatic pressure of 250 lbs. to the square inch.

4. *Piston and Rings.*—The piston and piston rings to be of approved pattern. The piston must be either made from a wrought steel stamping, or of metal similar to that used for the cylinders, and very tough. The material proposed to be used must be specified. The packing for the piston rods to be of approved pattern. A spare set of rings is to be supplied for each rod.

5. *Piston Rods.*—The piston rods are to be made of steel, to the Engineering Standards Committee's British Standard Specification, No. 8, Book 24, Class "B."

6. *Cross-head and Guides.*—To be of a simple type ; guide blocks or bars to allow of being taken up when worn. The lower guide bar to be preferably trough-shaped, giving as large a width of bearing as possible to a phosphor-bronze slide on the cross-head. The cross-head pin to be made from the best Yorkshire iron, and case-hardened. Bearing and rubbing surfaces, when of wrought iron or mild steel, must be case-hardened to a depth of not less than $\frac{1}{32}$″, according to the wear on the respective parts. The depth of the hardening to be proved by means of test pieces placed in the case. For quality of wrought iron or mild steel, *vide* paragraph 62.

7. *Connecting Rod.*—The connecting rod to be of best Yorkshire iron, from one of the four recognized makers, or mild steel ; in the latter case the material to be to the Engineering Standards Committee's British Standard Specification, No. 8, Book 24, Class "B." For quality of wrought iron, *vide* paragraph 62.

Both end brasses to be capable of easy adjustment and renewal, and to be fitted brass to brass.

8. *Crankshaft.*—The crankshaft to be made from a single piece of steel, the material to be to the Engineering Standards Committee's British Standard Specification, No. 1, Book 24. Brasses of main bearings to be capable of easy adjustment and renewal.

9. *Crankshaft and Motion Shaft Brackets.*—The crankshaft and motion shaft brackets to be secured to the frame plates by hard steel rivets, turned to a good driving fit, and riveted over cold.

10. *Flywheel.*—The flywheel to be so arranged if possible that it will drive a belt to the front or back clear of all gearing.

11. *Eccentrics.*—The eccentrics should be of cast iron or formed on the crankshaft, solid and keyed to the shaft.

12. *Straps.*—The straps must be of gunmetal or the finest cold blast iron, butt joint to the rod.

13. *Eccentric Rods.*—The rods must be of wrought iron or steel, forked at the little end to take the link, and the eyes case-hardened. For quality of material, *vide* paragraph 62.

14. *Link Motion.*—The link, die blocks, pins, etc., to be of wrought iron or mild steel, case-hardened on all working surfaces; all hardening must extend to a depth of $\frac{1}{32}''$ and will be proved as for crossheads and guides. The proposed arrangement must be clearly shown on the drawing accompanying the tender. For quality of material, *vide* paragraph 62.

15. *Valve Spindles.*—The valve spindles must be of mild steel, the phosphor-bronze bushes to be so arranged as to be readily removable.

16. *Slide Valves.*—To be of best gunmetal or cold blast iron accurately faced to the slides and connected to the spindles by gunmetal check nuts on both sides, or similar suitable arrangement.

17. *Indicator Gear.*—One set of indicator gear to be supplied to enable diagrams to be taken from both cylinders. Fittings on the cylinders to be provided on each engine.

18. *Governor.*—A governor to actuate a throttle valve is to be provided. It must be sensitive and steady in action, capable of being adjusted to varied speeds, and of being securely locked so that this adjustment cannot be tampered with by the driver on the road.

19. *Lubrication.*—Ample lubrication is to be provided for all working parts. All lubricators to be of ample dimensions.

20. *Pipes.*—All pipes to be fitted with drain cocks.

21. *Shafts and Axles.*—All shafts and axles to be made of steel, in accordance with the Engineering Standards Committee's British Standards Specification, No. 2, Book 24.

22. *Gears.*—A safety arrangement to be fitted to prevent the gears accidentally coming out of mesh when on the road. All gears to be capable of being thrown out of mesh, and a safety device fitted if possible, so that no two gears can be enmeshed at the same time.

The gear wheels to have accurately shaped teeth. The gear wheels to be made of cast steel, in accordance with the Engineering Standards Committee's British Standard Specification, No. 10, Book 24, Class "A."

23. *Compensating Gear.*—Compensating or differential gear must be provided for the driving wheels, the pinions of which shall be fitted with case-hardened pins and phosphor-bronze bushes. The material for the differential gear wheels and pinions shall be similar to that described for gears, *vide* paragraph 22.

24. *Driving Wheels Locking Device.*—Provision must be made for rapidly and readily locking the driving wheels together; if possible this should be arranged to be carried out without the necessity arising for leaving the footplate.

25. *Wheels.*—The wheels are to be as large as possible. The front wheels must not be less than 3′ in diameter nor the driving wheels less than 54″ in diameter. The driving wheels must be 12″ wide on the periphery, and must be fitted with plain wrought-iron road strips of not more than 3″ in width, nor less than ¾″ deep, fixed diagonally on the periphery.

The tyre plates, if any, to be of steel, with a tensile breaking strength of from 42 to 48 tons per square inch and a minimum elongation of 18 to 12 per cent. on 2″ and carried on steel tee rings, the spokes are to be made with enlarged ends *without weld* fixed to the rings by rivets, their inner ends cast into strong iron bosses with phosphor-bronze removable bushes. The material for the tee rings and spokes shall be in accordance with the Engineering Standards Committee's British Standard Specification, No. 17, Book 24. Two oil pipes with brass caps are to be provided for each wheel and fitted on opposite sides of the boss; these brass caps to be fitted with keep chains.

Alternative quotations may be made for wheels of patterns or materials differing from the above, in which case a full description and detail of the tests the material will withstand must be also submitted.

26. *Springs.*—All springs are to be of the highest quality, acid open hearth steel, and to be in accordance with the Engineering Standards Committee's British Standard Specification, Nos. 6 and 7, Book 24.

27. *Brasses and Bushes.*—Brasses and bushes are to be of phosphor bronze which shall contain not less than 0·5 per cent. nor more than 2·0 per cent. of phosphorus, not less than 8 per cent. and not more than 12 per cent. of lead or other approved material. The material will be subject to testing and to chemical analysis, which shall be conducted by the War Department; test pieces being provided to the satisfaction of the Inspecting Officer for the purpose free of cost to the War Department.

28. *Brakes.*—An efficient friction brake suitably fitted is to be furnished, capable of manipulation from the footplate. To be so geared so as to act directly on the hind wheels.

29. *Steering Gear.*—Steering gear worked from the footplate is to be provided for the forecarriage.

30. *Drag-Bar.*—The drag-bar arrangements must be so devised that the draught stresses are transmitted direct to the axle, no portion of them being communicated to the hind tank, and fitted with a spring attachment of approved design.

31. *Pushing Bracket.*—A pushing bracket to be fitted to the forecarriage.

32. *Manipulation.*—All handles, etc., required for manipulation to be brought together so as to be conveniently worked by one man on the footplate.

33. *Boiler.*—The boiler must be of ample capacity for generating steam for the engine when under full load, of suitable strength for the working pressure, must be certified by the Manchester Steam Users' Association as fitted for the stated working pressure, and must conform to the War Department Boiler Specification attached where not herein otherwise specified.

34. *Grate Area.*—The grate area must be of such size as will enable the full power to be obtained from the engine when burning fuel that is only 50 per cent. coal, as compared with Nixon's Navigation.

35. *Boiler Plates.*—The barrel plates are to be of best acid open hearth mild steel, to British Standards Committee's Specification, No. 16, Book 24. Smoke-box tube plate and fire-box tube plate to be of the same material as the barrel plates.

36. *Safety Valve.*—A safety valve of approved pattern to be fitted.

37. *Pressure Gauge.*—A dial pressure gauge with syphon drain-cock and stop-cock to be fitted. A lamp bracket to be fitted so that the dial can be read at night.

38. *Test-Cock.*—A test-cock of approved pattern, and to the Manchester Steam Users' Association Standard, is to be fitted for use with the pressure gauge.

39. *Gauge Glasses.*—Two water-gauge glasses and fittings are to be provided, one of automatic asbestos-packed "Klinger" or similar pattern, and the other of ordinary pattern, both with solid drawn waste-pipe.

40. *Blow-off Cock.*—A blow-off cock, all gunmetal, with double glands asbestos-packed, is to be provided in a suitable position, to be easy of access, and secured against the possibility of screwing out of the shell.

41. *Manhole.*—If possible a manhole suitably strengthened, fitted with an internal cover, is to be provided in an accessible position.

42. *Mudholes.*—Ample mudholes and plugs in suitable positions, including one at the bottom of the smoke-box tube plate, must be provided.

43. *Fusible Plug.*—A fusible plug of approved pattern is to be provided.

44. *Water Level.*—A mark or plate, showing the level of the top of the fire-box, is to be fixed on the boiler front.

45. *Feed Pump and Injectors.*—One feed pump and one injector, or two injectors are to be provided.

46. *Water Lifter.*—A water lifter of approved pattern is to be provided, fitted complete with the necessary pipes, cocks, connections, and screw couplings for the hose-pipe. Brackets to carry the suction and delivery hose to be provided.

47. *Back Pressure.*—Back-pressure valves all in gunmetal, combined with screw-down valve, to be provided for both boiler feeds. These must be fitted with a suitable stop-cock, to allow of the valves being examined under pressure.

48. *Furnace Door.*—Furnace mouthpiece and doors to be of a simple pattern.

49. *Ash-Pan.*—The ash-pan damper door to be worked from the footplate.

50. *Blast.*—A steam jet is to be provided.

51. *Filling Plug.*—A gunmetal plug is to be provided in a suitable position for filling up.

52. *Plugs.*—Plugs to be of standard sizes, and with Whitworth Standard Threads.

53. *Canopy.*—A canopy must be provided extending over the footplate and engine, but clear of the chimney; to be fitted with side curtains of stout waterproof and fireproof material, and so arranged as to be readily removable.

54. *Winding Gear.*—To be fitted with a winding gear, with 100 yards of flexible galvanized steel wire rope of suitable strength; to be arranged with suitable sheaves, so that a fair lead may be obtained from the drum to front or rear of the engine, and from thence in any direction within an angle of 90° to either side of the front to rear centre line of the engine. The winding gear to be so arranged that the wire rope can be paid out from the drum while the engine is moving ahead.

55. *Water Tanks.*—The capacity of the water tanks to be 300 gallons, and that of the coal bunkers to be 4 cwt. All water tanks to be fitted with manholes and covers, so that any portion of the interior may be readily accessible. The tanks must be fitted with suitable baffle plates.

56. *Tool Box.*—A tool box, fixed in a suitable position, to be provided, fitted with padlock and key.

57. *Tools.*—The engine to be supplied complete with the following accessories :—

A complete set of case-hardened spanners.
A complete set of firing tools and shovels.
One suction and one delivery pipe for the water lift, together with the necessary screw couplings.
Tube brush and rod.
Adjustable spanner.
Hammer, chisel, and punch.
Jack, screw, lifting, 5 tons.
Filling up funnel.
3 extra fusible plugs.
6 extra gauge glasses and rings for the plain gauge glass, and 1 glass and 6 sets of washers for the "Klinger" gauge glass.
Road lamps of "Meteor" pattern.
1 set of spuds, frost spikes, bolts, and keys.
Tube expander.
2 drag chains.

58. *Drawings.*—A full set of detailed dimensioned drawings on cloth to be supplied.

59. Blue prints showing the general arrangement of the engine, detail of the boiler, and cross section through the hind axle to be supplied in duplicate with each engine, one set to be submitted with the tender.

60. *Boiler Test.*—The boiler will be tested by the Manchester Steam Users' Association, to whom drawings must be submitted through the inspection officer for approval prior to the commencement of any work.

61. *Tests.*—Every facility must be given to the Manchester Steam Users' Association's representative to enable him to carry out his inspection of the boiler.

62. All material, where not herein specified to the contrary, to be in accordance with General Specification No. 1, I.I.S.

63. All material which in the opinion of the Inspecting Officer is unsound, unsuitable, or defective, or on which the workmanship is inferior, is liable to rejection, and must at once be replaced by the Contractor free of cost to the War Department.

64. If, in the opinion of the Inspecting Officer, the engine as a whole or any part thereof fails to fulfil the requirements of this specification, the same will be rejected.

65. All testing required by the Inspecting Officer to be performed on the Contractor's or Sub-Contractor's premises, or off their premises if no proper facilities exist thereon, is to be done by them at their own expense as regards labour and materials, under the direction of the Inspecting Officer.

66. The Contractor shall provide on the spot without extra charge

all means necessary to enable the Inspecting Officer to ascertain that the dimensions, numbers, and weights of all parts are as specified, and that the work generally is correct.

67. *Finish.*—All bars, plates, angles, and bolts must be dipped in boiled linseed oil or otherwise thoroughly covered with it before being put together, and as soon as possible after this they must receive a coat of paint as may be directed by the Inspecting Officer.

68. *Painting.*—Before leaving the Contractor's premises every portion of the work must be painted as may be directed by the Inspecting Officer.

GENERAL.

69. *Road Tests.*—The engine on completion and before being taken over by the War Department will be subjected to the following working tests :—

1. To haul a load of 8 tons gross for a distance of 30 miles over ordinary roads and surfaces, with gradients not steeper than 1 in 12 without replenishing fuel or water. This to form part of test No. 2.
2. To haul a load of 8 tons gross for a distance not exceeding 50 miles at an average speed of 4 miles per hour over ordinary roads.
3. For winding, by winding a load of 10 tons gross up an incline of 1 in 8 or a proportionately greater load up a less incline.
4. To haul a load of 10 tons gross for a distance of not less than 1 mile on an ordinary road on the level at a speed of 5 miles per hour.

The load, fuel, labour, etc., for these tests to be provided by the Contractor free of all cost to the War Department.

70. *Delivery.*—The engine to be delivered f.o.r., Aldershot, to the Chief Inspector, Mechanical Transport, Army Service Corps Mechanical Transport Depôt, Aldershot, *viâ* Aldershot Town Station, London and South-Western Railway.

71. *Identification Sheets.*—An identification sheet, giving the maker's numbers and price list of all parts, to be supplied in duplicate with each engine. The prices quoted to be those at which the Contractor will undertake to supply such parts as may be required by the War Department from time to time within five years of the date of placing of the contract.

72. *Damage Prior to Delivery.*—Any injury or defect or loss of any kind that may arise during transit to destination to be immediately made good by the Contractor free of all expense to the War Department.

73. *Firms for Sub-Contracts.*—The Contractor shall submit for approval a list of the firms from whom it is proposed to obtain the

materials to be used in the construction of the engine. *British material is preferred by the War Department.*

74. When the firms have been duly approved, the Contractor shall forward to the Inspecting Officer a copy in duplicate of the orders placed with each and all of the said firms, in order that the necessary arrangements may be made for inspection during manufacture.

Price of 5-Ton Tractor.

The price of the above would be approximately :—

Delivered F.O.R., English port	£500	0	0
Packing for shipment and delivery	8	0	0
Roller parts	150	0	0
Packing and delivery F.O.B.	3	10	0

Performance in R.A.C. Trials, 1907.

In the R.A.C. commercial vehicle trials of last year three of such small steam tractors by different makers competed.

The course was 686 miles over main roads in England. The running days were 22. One hour daily was allowed for cleaning, adjusting, etc. They all ran in a perfectly trustworthy manner, with practically no involuntary stops, except for watering or causes not connected with the trustworthiness of the engines. They each hauled a gross load of 6 tons, and consumed respectively 9·2, 10·3, and 10·8 lbs. of best English coal per mile. The firms which entered these machines for competition provided the driving staff, which was of course the best possible.

Description of a Light 3-Cylinder Steam Tractor.

Perhaps the most powerful motor of this class on the market is one made with three cylinders, viz., one high pressure and two low pressure. The high-pressure cylinder is 4″ diameter, the small low-pressure one 5″ diameter.

The high-pressure and small low-pressure cylinders work on the same crank in tandem, the large low-pressure cylinder on a separate crank, the large low-pressure crank leading the high-pressure and small low-pressure one by a right angle. The steam exhausts from the high-pressure cylinder into the two low-pressure cylinders simultaneously.

Record of Test.

The following is a record of its test under supervision by impartial observers :—

The tractor weighed 6 tons 15 cwts. in working order.

A wagon 10 tons gross weight was hauled over heavy-made unmetalled ground.

Over a 29¼-mile run, with a gross load of 10 tons behind it, on average hard roads, with usual gradients, its average speed was 4·83 miles per hour. It consumed 17·28 lbs. best York coal per mile, equal to 1·728 lbs. per ton-mile of gross load.

Consumption for the 29¼ miles, 504 lbs. coal and 326 gallons of water.

The tractor hauled a gross load of 16 tons up a gradient of 1 in 10·7. It travelled at 6 miles per hour over several consecutive miles with a gross load of 10 tons behind it. A load of 10 tons was hauled up a gradient of 1 in $5\frac{1}{2}$, on a partially metalled road, with the winding drum.

This engine would cost, delivered F.O.R. English port, £630 0 0
Packing for shipment and delivery F.O.B. 8 0 0

Trailers.—Trailing wagons for tractors are made of many sizes and shapes to suit various loads. It is important that they have very efficient brakes; otherwise, when turning a corner downhill, the trailer may slew the tractor off the direction in which it is travelling by skidding the driving wheels sideways. Trailer Wagons.

The following is a maker's description of their standard type of trailers:—

Latest improved traction wagon, constructed throughout of specially selected and well-seasoned timber. The main frame, bolsters, and axle beds are of oak, forecarriage of ash, all strongly framed and bolted together; the sides and ends of best dressed boards with iron tongues, the sides fitted with strong wrought-iron strap hinges to let down the whole length, the ends fixed by oak posts in wrought-iron sockets, and both the sides and ends can be removed when required.

The wagon is mounted on wheels constructed with tee section steel rings, with hard steel tyre plates, wrought-iron forged spokes, and cast-iron boxes fitted with reversible bushes and sand caps; through axles of best wrought-iron or hammered steel, fitted with strong caps and pins. The wagon is fitted with powerful screw-friction brake acting on the hind wheels, strong through drawbar with buffer springs, obviating jar and shock when starting and when ascending or descending hills, fitted with sloping jaws and pin at back end for coupling the wagon in train, and a strong triangular dragbar provided for forecarriage end; complete in all respects ready for work.

	4-ton Wagon.	6-ton Wagon.
Length and width of body outside...	11′ 9″ × 6′ 0″	12′ 3″ × 6′ 4″
Depth of sides and ends	1′ 9″ & 2′ 3″	2′ 0″ & 2′ 6″
Diameter and width of hind wheels	3′ 6″ × 6″	3′ $7\frac{1}{2}$″ × 8″
Diameter and width of front wheels	3′ 0″ × 6″	3′ $1\frac{1}{2}$″ × 8″
Weight of wagon	about 43 cwts.	about 55 cwts.
Price.		
Delivered F.O.R. English port ...	£65 0 0	£75 0 0
Extra if mounted on best laminated steel springs	£10 0 0	£10 0 0
Packing for shipment and delivery F.O.B.	£2 0 0	£2 0 0

Motors for Fast Traffic.

For traffic consisting of loads up to 3 tons, requiring a faster speed than an average of 5 miles an hour, the internal combustion engine, burning petrol, is most suitable, and a resilient tyre is a necessity. Internal combustion engines, starting on petrol and running on paraffin when warm, have been successfully run, but require very exceptionally skilled drivers.

The same remark applies to steam-driven engines with flash generators, and these two types may be considered as unsuitable for work in India, at any rate in their present state of development.

The construction of a petrol motor chassis for commercial work is totally different from that of a pleasure car. It is subject to much greater strains, runs on solid tyres, and carries infinitely greater loads than a pleasure car, with the same power of engine.

The commercial vehicle for heavy loads is too often built with gear allowing an objectionably high speed of road wheels, resulting in wasteful wear of both vehicle and road. The cost of upkeep increases very rapidly with increase of road speed, and though the true economic road speed has not yet been determined, varying as it does for different conditions of road surface, etc., high maximum road speeds should be avoided. A system of control, whereby the speed of the engine is governed by the speed of the road wheels, should be fitted.

A striking feature of the late R.A.C. commercial vehicle trials was the successful use of rubber tyres on vehicles carrying loads up to 5 tons, and weighing over 4 tons empty ; and there is no doubt that the quality of rubber tyres has improved immensely in recent years. It is very doubtful however whether any vehicle, weighing over, say, $3\frac{1}{2}$ tons empty and carrying 3 tons load on rubber tyres, would be economical in India. In France mounting any vehicle of over 3 tons carrying capacity on rubber tyres has been practically abandoned.

It should be remembered that heavy loads cause great wear on rubber tyres, not merely owing to the crushing and tearing due to the weight of the vehicle and friction on the road surface, but owing to the work on them they become hot, resulting in a softening of the rubber.

There is no reason whatever why the internal combustion petrol engine, as made for work in England, should not be as successful in a hot country like India as it is in a cold one.

The only difference in construction necessary is the provision of a more efficient cooling system for the engine than is usually fitted for English work. And this is a point in construction that is by no means always efficient in engines designed for English work. It is not a matter involving any great difficulty, merely necessitating more water-tank capacity and a larger circulating pump and radiators than that used in England.

The following points should be carefully guarded against in running high-speed petrol motors :—

1. Overloading.
2. Too high a road speed, especially on bad surfaces.
3. The engine should have plenty of power to do its work without continual change of speed gears. It should be remembered that, for work in a hilly country, the efficiency of the internal combustion engine falls considerably at high altitudes. This is due to the air being rarified, having a less volume of oxygen to a given cubic space, with the result that the explosive mixture is compressed to a less density before explosion in the cylinders.

Internal combustion engines by the best makers have now been standardized in their main points for some years, and have reached a point of great trustworthiness. Many large retail shops do much of their collection and delivery work by this means, finding it more profitable than by either rail or horse haulage. In addition, many mail services are now run by road motors. Some of these are London to Cambridge (62 miles), London to Brighton and return, London to Hastings and return, Eastbourne to Tunbridge Wells and return, London to Ipswich and return, London to Dover and return, London to Folkestone and return, London to Redhill and return, Northampton to Itching. These are given to show that the modern petrol motor, when properly treated, is fitted for services requiring the utmost regularity in running. An English railway, which goes in largely for road services with petrol motors, manages an average of 3,000 miles per involuntary stop with its buses and char-à-bancs. A halt of less than eight minutes is not considered a stop in this calculation.

The following is a brief description of the chassis most favoured by this railway, and now exclusively ordered in preference to other makes :—

Frame.—2-ton frame, fitted with 16/20 H.P. petrol motor (some cars have 3-ton frames). Specification of a 2-Ton Chassis of Good Type.

Motor.—Four cylinders, developing 20 H.P. at 800 revolutions ; maximum speed, 1,000 ; bore of cylinders, 105 m/m × 130 stroke.

Governor and Governing Gear.—The controlling of the speed of the engine is on the inlet mixture, that is, it is governed by throttling the mixture. The exhaust valves are positive acting.

Gear Box.—Canstatt type, 4 speeds forward, viz., 3, 5½, 7, and 12 miles an hour, at normal revolutions per minute of motor; also 1 reverse, which, in conjunction with the flexibility of motor, will give any speed from 1 to 12 miles an hour.

Transmission.—By cone clutch to gear box, and then by shaft with universal joints to differential cross shafts direct on to the internal gear rings on driving wheels.

Wheels.—Diameter of front wheels, 2′ $7\frac{1}{2}''$ × $2\frac{7}{8}''$ wide.

„ rear „ 3′ $5\frac{3}{8}''$ × 4″ „

Tyres.—Solid rubber twin on back wheels, single on front wheels.

Lubrication.—To the cylinders and cranks, to be supplied by pressure feed lubricators, within easy view of the driver, having regulators which can be adjusted to suit the requirements of each bearing.

Cooling.—Canstatt marine type cooler, holding 2 gallons of water.

Ignition.—Sims Bosch low-tension magneto.

Carburettor.—Float-feed.

Pump.—To rotary gear, driven at 1,400 revolutions per minute.

Brakes.—There are two brakes, one acting on the first intermediate gear shaft, and one pair of brake blocks acting on back road wheels, also an expanding brake on rear wheel double-acting, operated by foot lever, and also continuous by means of ratchet.

The following is an extract from the accounts, showing what such motors cost to run :—

Some Trustworthy Records of Running Costs.

For 2-ton Vehicle.	Pence per Car-Mile.
Drivers, cleaners, conductors, inspectors, etc.... ...	3·40
Tyres	2·00
Petrol	1·29
Car maintenance repairs, etc., including depreciation at 20 % per annum	2·00
Lubrication	0·46
Lighting	·04
License	·15
Sundries, advertising, head office salaries, etc. ...	1·06
Total	10·40 pence

In the above calculation petrol is taken at $8\frac{1}{4}$d. per gallon, giving 6·4 miles per gallon.

Driver's wages are at 36s. per week, and cleaners at 20s. per week.

The cost of such a vehicle would be anything from £735, if fitted as a lorry, to £850, fitted as a superior type of omnibus.

Such vehicles, with specially skilled drivers, can be worked with full load on ordinary English roads on an average of 8·32 miles per gallon of petrol, equal to 1d. per car-mile at $8\frac{1}{4}$d. per gallon, 35·6 miles per pint of lubricating oil, and 63·3 miles per lb. of lubricating grease. This latter record is from the judge's report on the R.A.C. trials of last year, over a distance of 1,139 miles in 22 days, the vehicle being under full load night and day, and is instructive as showing the difference in fuel consumption between the driving of specially skilled and good average drivers.

The following may be taken as approximate dimensions of such vehicles :—

	3-ton Vehicles.	2-ton Vehicles.	1-ton Vehicles.
Length over all	20′	18′	14′
Width ,, ,, ...	7′	$6\frac{3}{4}$′	$5\frac{1}{2}$′
Number of cylinders	4	4	2 or 4
Brake horse-power	30 to 40	25	18 to 20
Radius of action on fuel tank...	100 miles	100 miles	120 miles
Consumption of water... ...	a few gallons	daily.	

The following descriptions of the bodies fitted to 2-ton vehicles used by a large English railway will give an idea of the capacity of such :— Carrying Capacities for Passengers, etc.

1. Open wagonette bodies, seating 22 passengers and driver.
2. Luggage omnibus bodies, seating 18 passengers and driver, and carrying 15 cwts. of luggage, parcels, and light goods on the roof and rear platform.
3. Double-deck omnibus bodies, seating 16 passengers inside and 18 outside.
4. Observation car or char-à-banc bodies, seating 24 passengers and driver.
5. Composite goods, mail and omnibus bodies, seating 10 passengers inside, 2 beside driver, with a compartment between the driver's seat and the passenger compartment, which can be used for either luggage, mails, or goods, or by means of flap seats for passengers desiring to smoke. This compartment will seat 8 passengers.

On a 1-ton chassis with a 2-cylinder engine developing 14 H.P. with a maximum speed of 15 miles an hour, an omnibus type of body is fitted, accommodating 15 passengers and 8 cwts. of luggage.

Manufacturers will of course fit any design of body required. Designs should be as light as possible and arranged to give as great a proportion of the load as possible on the driving wheels, which are the rear pair.

The following may be taken as a liberal estimate of the cost of running petrol-driven vehicles on average English roads :—

Estimate of Running Costs for Various Types.

	Carrying Capacity.		
	3-ton Vehicle.	2-ton Vehicle.	1-ton Vehicle.
Weight of vehicle empty ...	$3\frac{1}{2}$ tons	3 tons	$1\frac{1}{2}$ tons
Useful load	3 ,,	2 ,,	1 ,,
Gross weight under load ...	$6\frac{1}{2}$,,	5 ,,	$2\frac{1}{2}$,,
Maximum weight on any axle	$4\frac{1}{2}$,,	3 ,,	$1\frac{3}{4}$,,
Daily mileage at 7 hours ...	52	63	87
Average speed on road, miles per hour	7 to 8	8 to 10	10 to 15
Annual mileage at 260 working days	13,520	16,380	22,620
Annual net ton-mileage, allowing return journey empty ...	20,280	16,380	11,310
Fuel consumption per gross ton-mile	·03	·03	·04 gals.
Lubricating oil consumption per mile	·1 pint	·1 pint	·1 pint
Annual cost of petrol, allowing return empty	£72	£70	£64
Annual cost lubricating oil ...	£25	£31	£42
Drivers' wages per annum ...	£93	£93	£93
Cleaners' wages per annum ...	£52	£52	£52
Annual cost of small stores, cotton waste, cleaning materials, etc.	£50	£50	£40
Tyres	£141	£137	£165
Depreciation at 20%	£170	£150	£110
Capital outlay	£850	£750	£550
Repairs at 10% on capital outlay	£85	£75	£55
Housing and office expenses, etc., at 5% on capital outlay	£43	£38	£28
Allow 10% for contingencies ...	£85	£75	£55
Total annual cost	£816	£771	£704
Cost per net ton-mile	9·6	11·3	14·8

In this estimate the daily mileage is not of course the maximum that can be done, especially if a relief of drivers is provided. It is evident that the daily mileage has a great influence on the cost per ton-mile.

The average speed on the road is the highest that can be economically attained on good average roads, and depends on the quality ot the surface of the road and the exigencies of traffic requiring halts. Two hundred and sixty working days is taken in the year to allow for Sundays, and one other day per week off for cleaning. In India it should be possible to run a larger number of days in the year.

The calculation is for half the daily mileage empty and the remainder with full load. Anything over or less than this will correspondingly affect the cost per ton-mile.

The fuel consumption is taken at 5, 6·7, and 10 miles to the gallon with full load for the three different types of vehicles respectively.

In the late R.A.C. trials such vehicles attained a fuel consumption of 9·05, 9·91, and 16·25 miles per gallon respectively, with specially skilled drivers, over 1,000 miles trial under full loads.

Petrol is taken at 8¼d. per gallon.

Lubricating oil consumption can be reduced to ·05 pints per mile with specially good drivers.

Its cost is taken at 3s. per gallon.

Tyres are taken at 2¼d., 2d., and 1¾d. per car-mile respectively for the three classes. On Indian roads corresponding to good average English ones this should not be exceeded. Many manufacturers in England contract to maintain tyres at these rates. Of course with a less daily mileage the deterioration due to weather, light, oil droppings, etc., would be a larger proportion of total wear, so that the cost per car-mile would be somewhat higher.

Depreciation is allowed for, on the assumption that the vehicle would last five years only, and in addition 10% is allowed for repairs. Depreciation depends entirely on the quality of the driver and the way in which he is supervised, whether the vehicle is habitually overloaded or not, whether repairs are promptly effected, etc., and a good class of vehicle should last considerably longer if treated well. Moreover, by replacing worn parts there is no reason why a vehicle should not be kept running efficiently for an indefinite number of years.

Capital outlay depends largely on the type of body fitted. A superior class of omnibus body would cost anything up to £100 more than the figures given.

Cost of the Motor Cab.

Type of Vehicle.

A concise estimate of the costs of running the motor-cab type of vehicle may not be out of place, for though the motor cab has little future as a factor in feeding traffic to railways in India, yet the motor-cab type of chassis is used largely for light loads requiring fast travel, such as quick delivery work, and for private car work requiring a chassis up to rough work such as would be required by a railway official in India travelling off the line of rail in connection with the traffic canvassing, etc. The figures given are for an English cab as run in London now, and may be taken as a generous estimate of cost.

Such vehicles cost about £350 fitted as a cab or £325 fitted as a covered delivery van. For speeds of 20 miles an hour they must have pneumatic tyres, but for lower speeds solids may be used for the rear wheels, in which case the engine should be governed so that it is impossible to drive more than 15 miles an hour. The vehicle would weigh approximately 1 ton, and be fitted with a 2 or 4-cylinder engine of about 12 H.P., and would carry ½ ton.

Consumption of petrol for pneumatic tyres would be about 20 miles to a gallon.

Running costs of motor cab for one year :—

	£	s.	d.
Petrol	55	0	0
Extra for test running of engine	3	0	0
Driver at 36s. a week...	93	0	0
Oils and greases	12	6	0
Depreciation $33\frac{1}{3}$ %	116	13	4
Body repair and upholstery	25	0	0
Pneumatic tyres	150	0	0
Garage and cleaning	52	0	0
Replacements and repairs	52	0	0
Total	558	19	4

Petrol is taken at 11d. per gallon with the cab travelling 20 miles to a gallon. With solid tyres on the rear wheels the consumption would be probably 15 % more.

The daily mileage is taken at 80 miles for 300 days=24,000 miles a year.

Tyres are taken at $1\frac{1}{2}$d. per mile.

With solid tyres on the rear wheels the cost might be reduced to 1d. per mile.

Depreciation is taken at $33\frac{1}{3}$ %, though if replacements and repairs are carried out as required, a cab should be in as good condition at the end of six years as it was when new.

Garage and cleaning is taken at £1 per week.

Replacements and repairs at 15 % per annum.

It must be understood that this type of vehicle has been running too short a time for actual figures to be obtained. This estimate works out at $5\frac{1}{2}$d. per mile.

The following description of an Indian traffic route, with an estimate for introducing mechanical traction on it, will probably give a better idea of the possibility of this means of transport in India than anything in the foregoing report.

The Shillong-Gauhati Road as a Route for Mechanical Road Transport.

The route in question is the road between Gauhati, the headquarters of the district of Kamrup, on the south bank of the Brahmaputra, and Shillong, the sanitarium and summer headquarters of the Government of Eastern Bengal and Assam, in the Khasi Hills. The road runs practically due north and south. The northern terminus, Gauhati, is served by the Assam Bengal Railway and the River Steam Navigation Co., and will in a few months be served by the Eastern Bengal State Railway. Gauhati is 200′ and Shillong approximately 4,900′ above sea level.

General Description of Road.

The road is 64 miles long, hilly the whole way, except for about

7 miles near Gauhati. This 7 miles is in some places on embankment which is not high enough, and requires to be raised to 3′ above the highest known flood.

It is fairly well metalled for its whole length for a width of about 12′ in the centre, and it is some 16′ wide. All bridge openings are constructed to carry an 11-ton steam roller. Good granite and trap rocks are plentiful for road metalling.

Grades run to about 1 in 15 as a maximum at present, but great improvements are now being made whereby corners are being cut off to allow better view to drivers of vehicles, and the grades are being reduced to a maximum of 1 in 20. Sharp curves are being eliminated, so that the sharpest will be 50′ radius.

The steepest grades are at the Shillong end, and consist of some 6½ miles, rising towards Shillong, averaging 1 in 22·5 with a ruling grade of 1 in 20.

Water is plentiful over the whole route, which is well wooded. There is an unopened coal field some 5 miles west of the road at mile 54½ from Gauhati. It is said to be good steam coal, but its extent is not known, and earthquakes are frequent, which would prevent mining on a large scale. It is possible however that coal could be brought to the road from this field advantageously for the purpose of mechanical transport.

The road between the termini is unhealthy for men and animals. Malaria is virulent and anthrax carries off large numbers of draught animals yearly. The terminal stations of Gauhati and Shillong are healthy. Nangpo is a small settlement half-way between Shillong and Gauhati. It is provided with telegraph and post offices and a rest house. Labour is scarce and inferior; all draught animals and most of their drivers are imported.

Traffic is mostly uphill for goods, as most of the food supplies of Shillong are imported from the plains. This varies from 9 to 15 tons a day throughout the year as follows:— Traffic. Uphill Goods.

	Total.		Average Daily.		Total.		Average Daily.
	Maunds.	Tons.	Tons.		Maunds.	Tons.	Tons.
Jan. ...	7680	274	8·8	July ...	11344	405	13·1
Feb. ...	8976	321	11·5	Aug. ...	9136	326	10·5
Mar. ...	8912	318	10·2	Sept. ...	12912	461	14·9
April ...	9568	342	11·4	Oct. ...	12656	452	14·6
May ...	11824	422	13·6	Nov. ...	8336	298	10·0
June ...	9040	323	10·8	Dec. ...	9488	339	10·9
	Total	2,000 tons.			Total	2,281 tons.	

Net total of up traffic, 4,281 tons.

These are actual quantities arrived at by census of traffic on the road, which consists of miscellaneous goods of all kinds.

Downhill Goods.

As regards downhill traffic, no census is available, but the local authorities estimate it as half the uphill traffic from the middle of May to the middle of November, and one-quarter of the uphill traffic for the remainder of the year.

Thus the amount is :—

	Total.		Average Daily.		Total.		Average Daily.
	Maunds.	Tons.	Tons.		Maunds.	Tons.	Tons.
Jan. ...	1920	68·6	2·2	July ...	5672	202·6	6·5
Feb. ...	2244	80·1	2·9	Aug. ...	4568	163·1	5·3
Mar. ...	2228	79·6	2·6	Sept....	6456	230·6	7·7
April ..	2392	85·4	2·9	Oct. ...	6328	226·0	7·3
May ...	4434	158·4	5·1	Nov. ...	3126	111·6	3·7
June ...	4520	161·4	5·4	Dec. ...	2372	84·7	2·7
	Total	633·5 to	ns.		Total	1018·6	tons.

Net total of down traffic, 1,652 tons.

This traffic consists mostly of potatoes, the remainder being raw hides, personal effects, and miscellaneous articles.

Existing Transport for Goods.

This goods traffic is at present dealt with by bullock carts, carrying an average of 16 maunds, and as much as 20 maunds maximum. They take about one week to do the journey, but owing to losses, damage, and pilfering *en route*, delay at terminal stations, and breakdowns on the road, goods may take anything up to two months, especially in the case of articles awkward to handle.

Existing Goods Rates.

The freight at present varies between Rs.2 2 0 per maund ($=14\frac{7}{8}$ annas per ton-mile) in the busy season, to Rs.1 4 0 per maund ($=8\frac{3}{4}$ annas per ton-mile) in the slack traffic season.

In addition there is a terminal charge of 2 annas per maund at each end, which includes delivery.

The year's contract for the Public Works Department stores for the last year was Rs.1 11 0 per maund (=11·8 annas per ton-mile). Of this the cost of loading, unloading, and delivery would be 1 anna per maund. These rates are all for uphill loads. For downhill traffic the rate varies from Rs.1 8 0 per maund ($=10\frac{1}{2}$ annas per ton-mile) to 8 annas per maund ($=3\frac{1}{2}$ annas per ton-mile) plus terminal charges as for uphill traffic. The lower rates downhill are due, firstly, to the grade being mostly with the traffic, and secondly, because there is competition for return loads, and there are insufficient goods for all carts to return loaded. But these rates for return traffic are dependent on the carts which deal with it coming up the hill with a full load at high rates.

Fast Goods.

In addition to the above, there is 1 ton of goods uphill and ½ ton downhill daily throughout the year, requiring quick transit. This is at present carried by bullock cart, with reliefs of bullocks and drivers, taking two to three days for the single trip.

It consists mostly of personal effects of and supplies for Europeans. The freight on such traffic is Rs.2 per maund (=14 annas per ton-mile) each way, the whole year round, plus 2 annas per maund at each terminal.

Native Passengers.

These carts also carry native passengers at Rs.6 each for the single journey. Such passengers are carried sitting or lying among the goods in the carts.

The following is the record of census of such passengers for 1 year:—

	Total.		Average Daily.	
	Up.	Down.	Up.	Down.
January	40	41	1·3	1·3
February	50	33	1·8	1·2
March	85·5	37	2 8	1·2
April	118·5	40	3·9	1·3
May	76	44·5	2·5	1·4
June	96	86	3·2	2·9
July	70	119·5	2·3	3·9
August	131·5	71	4·2	2·3
September	103·5	81·5	3·5	2·7
October	56·5	237·5	1·8	7·7
November	58·5	134·5	1·9	4·5
December	47·5	46·5	1·5	1·5
Total	933·5	972	—	—

Effect of Present Transport Arrangements on Trade.

The goods traffic is at present in the hands of a few Marwari merchants, who form a ring to keep up the prices of food stuffs and supplies in Shillong. This, with the high freight rates, makes Shillong one of the most expensive stations in India, and hinders the development of the trade of the country.

Also, as there is no system of through booking between Shillong and the railways and steamers at Gauhati, everyone in Shillong has to employ agents in Gauhati to forward goods, and there is difficulty in substantiating claims for loss or damage of goods in transit, owing to the impossibility of proving which carrying agency is responsible for it. This leads to expense and delays, especially to goods sent under the value payable system.

Mail and European Passenger Traffic.

Other traffic on the road consists of mail letters and parcels, and passengers, mostly Europeans. This traffic is carried by pony tongas, involving 17 reliefs of ponies in the 64 miles. The journey takes about nine hours, inclusive of some three-quarters of an hour halt half-way for refreshments.

This service is subsidized by Government to the extent of Rs.3,800 per month. For this subsidy the contractor for the service has to carry anything up to a total of 6 maunds of mails each way daily. Any mails in excess of this quantity on any day in either direction are paid for at the rate of Rs.7 8 0 per maund if carried by tonga, or Rs.2 per maund if by fast bullock cart.

These rates are equal to Rs.4 9 11 per ton-mile for the first 6 maunds, and Rs.3 4 6 per ton-mile for anything beyond 6 maunds if carried by tonga, or 14 annas per ton-mile if by bullock cart.

Government also agrees to purchase the draught animals, tongas, and other necessary transport plant in the event of the contract being closed or handed to another contractor. The contract is a yearly one, terminable in March of each year.

The passenger fare for the single journey by tonga is Rs.16, with no reduction for return. Passengers are allowed ½ maund luggage free, any excess being charged at Rs.7 8 0 per maund. Calculating a passenger at 2 maunds, these rates amount to Rs.2 12 10 per ton-mile for passengers, and Rs.3 4 6 per ton-mile for luggage, in excess of ½ maund a head.

The contractor at present working this traffic has lately introduced a few motor cars to supplement his tonga service. Being a more or less illiterate native merchant, with no technical knowledge or training, his motors do not work trustworthily.

He had last spring a total of four cars, including three different makes, and they were all unsuitable for the work. As a consequence, he is not allowed to carry the mails by motor, and many passengers avoid them in favour of the tongas. Also, the subsidy he receives from Government is higher than it need be if the service were run efficiently, and the rates of carriage are excessive, to cover the costs of waste and ignorance.

The Government possesses no officials with a knowledge of what such a service ought to cost or what type of motor is most suitable. The subsidy therefore is fixed by guesswork, and while under agreement to purchase his plant in the event of any change in contractors, the Government have no means of checking his purchase of rubbishy or unsuitable motors.

It is probable therefore that the traffic of the country will in a short time be overburdened with heavy rates of freight, caused by the necessity of earning a profit on an unnecessarily high capital expenditure in motors, originally unsuitable and wastefully worn out.

The present cost of buying out the plant of the existing contractor has been estimated at Rs.62,000.

The true value would probably be nearer Rs.35,000.

The following are the quantities of mails carried during one year, derived from Government records :—

	By Tonga Maunds.		Fast Bullock-Cart Maunds.	
	Total.	Daily Average.	Total.	Daily Average.
January, up	181·03	5·84	14·03	0·45
„ down	182·18	5·88	24·48	0·79
February, up	170·98	6·11	18·40	0·66
„ down	179·91	6·43	3·25	0·12
March, up	201·73	6·51	17·60	0·57
„ down	215·06	6·94	19·29	0·62
April, up	182·10	6·07	26·15	0·87
„ down	130·58	4·35	Nil.	Nil.
May, up...	169·33	5·46	48·98	1·58
„ down	195·98	6·32	4·63	0·15
June, up	163·05	5·44	41·05	1·37
„ down	203·53	6·78	12·25	0·41
July, up	170·31	5·49	26·40	0·85
„ down	117·48	3·79	4·10	0·13
August, up	98·98	3·19	88·48	2·85
„ down	102·12	3·29	30·70	0·99
September, up	93·28	3·11	96·68	3·22
„ down ...	97·00	3·23	20·50	0·68
October, up	111·10	3·58	37·35	1·20
„ down	100·38	3·24	22·98	0·74
November, up	163·78	5·46	27·63	0·92
„ down ...	182·33	6·08	7·05	0·24
December, up	194·95	6·29	21·05	0·68
„ down... ...	112·58	3·63	14·05	0·45

Total up by tonga, 1900·62 maunds.
„ down „ 1819·13 „
Total up by bullock cart, 463·80 maunds.
„ down „ 163·28 „

The following is a record of passenger traffic by tonga for one year :—

	Passengers Up.		Passengers Down.	
	Total.	Daily Average.	Total.	Daily Average.
January	139	4·48	88	2·84
February	85	3·04	86	3·07
March	174	5·61	98·5	3·18
April	232	7·73	128	4·27
May	243·5	7·85	118·5	3·82
June	222·5	7·42	167·5	5·58
July	137	4·42	186·5	6·02
August	164·5	5·31	117·5	3·79
September	213	7·10	165	5·50
October	211	6·81	305	9·84
November	114·5	3·82	155·5	5·18
December	108	3·48	155·5	5·02
Total	2044	—	1771·5	—

Estimate for Mechanical Transport.

The following is a scheme with estimate for dealing with the whole traffic on the road by mechanical means, under the control of one of the railways which run into Gauhati. The most convenient of these two lines is the Eastern Bengal State Railway, for though the south bank of the Brahmaputra is considered the sphere of influence of the Assam Bengal Railway, it is wrongly so. The trade of Gauhati and Shillong is mostly with Calcutta and Bengal, *viâ* the north bank and downstream of the Brahmaputra, which is served by the Eastern Bengal State Railway, and not by the Assam Bengal Railway.

So that it is more to the interest of the former line than the latter to develop the trade of the route, and the position of the river is inconvenient for it to be made the boundary between the two railway spheres of influence.

I have divided it into two estimates—first, of goods and native passengers, by small traction engines and trailing wagons ; and second, for dealing with mails, parcels, and European passengers, by means of petrol motor cars. The road maintenance should be taken over from the Public Works Department, and carried out by the administration working the transport service.

The advantages of this are discussed early in this paper, and in this case there is the additional advantage of cheapening the cost of administration by having one official in charge of both.

I failed to obtain any accurate estimate of the cost of maintenance of the road under present arrangements. One estimate, from a source which should be trustworthy, gave Rs.100,000 per annum; another, from an equally trustworthy source, was Rs.50,000.

However, with steam tractors working in the slack traffic season as road rollers and used for breaking and hauling a better class of road metal than is used at present, maintenance should be cheaper than it is now, especially if a more prompt system of payment for work done were enforced, and delays in sanction of expenditure avoided.

So that if the service were subsidized to the extent of the present cost of road maintenance, to allow for the railway undertaking it with the transport service, there should be no loss to the railway taking over the work. The actual present cost does not affect this estimate.

The capital expenditure on the tractor service would be :—

Mechanical Transport of Goods Capital Expenditure.

		Rs.
1.	10 tractors capable of drawing a net load of 5 to 6 tons at Rs.10,500 each	105,000
2.	14 trailer wagons of 6 tons capacity each, at Rs.1,500 each	21,000
3.	Shed accommodation at Gauhati	10,000
4.	„ „ „ Nangpo	3,000
5.	„ „ „ Shillong	5,000
6.	Workshop buildings at Gauhati	5,000
7.	„ „ „ Shillong	3,000
8.	„ tools „ Gauhati	4,000
9.	„ „ „ Shillong	3,000
10.	Goods go-down at Shillong	5,000
11.	Booking office at Gauhati	3,000
12.	„ „ „ Shillong	3,000
13.	Office of superintendent at Gauhati	10,000
14.	1 European mechanic's quarters, Gauhati ...	7,000
15.	1 traffic clerk's „ „ ...	3,000
16.	1 store „ „ „ ...	3,000
17.	6 drivers' quarters at Gauhati, Rs.3,000 each...	18,000
18.	6 brakesmen's quarters at Gauhati, Rs.400 each	2,400
19.	2 watchmen's „ „ „ Rs.400 each	800
20.	1 running room for drivers and brakesmen at Nangpo	2,000
21.	1 clerk's quarters at Nangpo	1,000
22.	1 native mechanic's quarters at Shillong ...	1,500
23.	1 station-master's „ „ „ ...	2,000
24.	4 drivers' quarters at Shillong, Rs.3,000 each ...	12,000
25.	4 brakesmen's quarters at Shillong, Rs.300 each	1,200
	Total	233,900

Of this amount 50 % of item 13 is debitable to road maintenance, as the one superintendent would control both it and the transport service.

25 % also would be debitable to the mail and passenger service.

Also 50 % of items 6, 7, 8, 9, 11, 12, 14, 15, 16, 19, 21, 22, 23 is debitable to the mail and passenger service.

	Rs.
This gives a total credit of	27,150
Leaving the capital expenditure at	206,750
Add 10 % for contingencies	20,675
Net total	227,425

The number of tractors required is taken at 10. This allows four pairs of two, each doing 32 miles a day, with a 6-ton trailer each, working two pairs up and two pairs down, and two spare for periodical cleaning and repairs.

With the provision of reliefs of drivers at Nangpo, it is possible that less than this number of engines would be able to deal with the traffic. But the same objections to pooling engines exist, as obtain in railway locomotive practice. However, in periodical short rushes of traffic they would be worked with reliefs. Such extraordinary traffic can be foreseen and provided for. In time of slack traffic spare tractors would be employed as road rollers, working stone crushers for metal and hauling stone for repairs.

Native passengers could be conveniently carried on benches supported on brackets horizontally and transversely behind the trailing wagons. If necessary, a light canvas tilt would be provided over such benches as shelter from rain.

Fourteen trailers are allowed, providing eight in continuous work travelling daily, two at each terminus loading and unloading, and two spare.

The price of tractors is high, as the most powerful and expensive on the market has been allowed for.

Working Expenses on Transport of Goods and Native Passengers.

In the following calculation of the working expenses of this tractor service, it is assumed that 80 % of the existing slow goods traffic, both up and down, would be attracted from the bullock carts plus all the fast goods traffic and native passengers.

The service would land goods in Shillong within 24 hours under normal circumstances, against a week or more by bullock carts, and as compared with two or three days by fast bullock carts.

Assam coal, equal to English coal for steam raising, costs Rs.10·80 per ton at Gauhati.

Good Khasi Hill steam coal costs Rs.21 per ton at Shillong. A coal depôt would be formed at Nangpo half-way along the road. This coal would be carried from Gauhati, and the average cost of coal on the route is therefore taken at Rs.18 per ton.

The total goods up traffic per annum to be expected is therefore $\frac{4}{5}$ of 4,281 tons slow goods plus 365 tons fast goods=3,790 tons, or 242,560 ton-miles.

The total goods down traffic will be $\frac{4}{5}$ of 1,652 tons slow goods plus 183 tons fast goods=1,505 tons, or 96,320 ton-miles.

The number of native passengers at present carried by bullock cart are 1905·5 per annum. Calculated at 2 maunds each, this gives 136 tons, or 8,704 ton-miles.

Taking the expenditure of fuel as 2 lbs. per gross ton-mile (including weight of engine and trailer, 9 tons), and that an average of eight tractors, each doing 32 miles daily, are required to deal with the traffic, the annual coal consumption amounts to $(242{,}560+96{,}320+365\times9\times8\times32)\ 2\div2{,}240+8{,}704\div1{,}120$ tons$=1{,}061{\cdot}2$ tons.

		Rs.
1.	The annual cost of coal therefore=	19,101
2.	Lubricating oil, at 11 annas per gallon and ·1 pint per tractor mile	803
3.	Small stores, cotton waste, firewood, etc. ...	3,000
4.	Lighting	1,000
5.	Depreciation on tractors at 12 % per annum ...	12,600
6.	" " trailers " 5 % " ...	1,050
7.	" " workshop tools at 5 % ...	350
8.	Repairs to tractors at 10 %	10,500
9.	" trailers " 8 %	1,680
10.	" buildings at 2 %	1,545
11.	Pay of superintendent, at Rs.1,500 per month	18,000
12.	" European mechanic, at Rs.450 " ...	5,400
13.	" 10 drivers, at Rs.150 a month each ...	18,000
14.	" 10 brakesmen, at Rs.15 " " ...	1,800
15.	" superintendent's office staff, at Rs.600 per month	7,200
16.	" 6 fitters, blacksmith, and carpenter, at Rs.60 per month each	4,320
17.	" traffic clerk at Gauhati, at Rs.50 per month	600
18.	" traffic clerk at Nangpo, at Rs.30 per month	360
19.	" station-master at Shillong, at Rs.80 per month	960
20.	" native mechanic at Shillong, at Rs.150 per month	1,800
21.	" 4 watchmen, at Rs.10 per month each	480
	Total yearly	110,549

In the above 50% of items 11 and 15 are debitable to road maintenance, and 25% to the mail and passenger service. This gives a credit to the above estimate of Rs.18,900.

Also 50% of items 7, 12, 16, 17, 18, 19, 20, 21 is debitable to the mail and passenger service. This gives a credit of Rs.7,135.

The year's working expenses then become ...	Rs.84,514
Add 10% for contingencies	8,451
Total	Rs.92,965

In this account the coal expenditure per gross ton-mile is taken at nearly double of best English practice. It is almost impossible to distinguish between repair charges and depreciation, as an engine can be practically rebuilt by repairing and replacing worn parts.

Some War Office tractors, the depreciation being calculated at 7%, should be scrap iron, but are still working efficiently.

The best staff obtainable would be necessary, and rates of pay are calculated which should attract such men. A first-class European English-trained head mechanic, with experience of steam and petrol road engines, is absolutely necessary. He should be engaged in England.

Earnings on Transport of Goods.

The gross earnings on goods to be expected are :—

338,880 ton-miles at 7 annas per ton-mile (as compared with 11·8 annas per ton-mile, P.W.D. contract rate for last year)	Rs.148,260
Plus 1905·5 passengers, at Rs.4 each	7,622
	Rs.155,882

Profit.

These results give a working cost of 4¼ annas per ton-mile of useful load, a net profit on working of Rs.62,917, or 27·7% on capital expenditure. This is with a reduction of 33% on existing rates for native passengers, over 40% reduction on upward goods rates, and downward rates equal to the average of present rates. It is anticipated that such rates would kill the bullock-cart traffic and be a great help to the trade of the country. It would not be advisable to reduce rates further until the effect of the traffic on costs of road repairs was ascertained. They could be considerably higher, and still drive the bullock carts out of competition.

European Passengers and Mails.

For the mail and passenger service a great deal depends on the number of mails required to be despatched and delivered daily. The local authorities estimate that one only would be required when the Eastern Bengal State Railway extension to Gauhati is open for traffic. In this case the whole of the daily mails and passengers, as per present traffic, can be dealt with by one 2-ton vehicle each way daily.

For the maximum number of passengers in either direction on any day is approximately 10.

Taking a passenger as 2 maunds weight plus ½ maund free luggage plus ½ maund excess luggage, the total maximum weight to be carried in any direction on any day of the year=30 maunds=1·07 tons.

The maximum weight of mails on any day in either direction during the year, including parcels, at present carried by bullock cart, is approximately 7 maunds=·25 tons. So that the total maximum weight that may be expected in any one vehicle is 1·32 tons. This allows room for increase in traffic and the growth of a local traffic in perishable goods requiring quick transport, *e.g.*, milk, fruit, etc., or the carrying of a few native servants in the vehicles with the European passengers' luggage.

Capital Expenditure for Transport of Mails and European Passengers.

The capital expenditure on the mail and passenger service would be :—

	Rs.
1. 3 2-ton petrol-driven motor vehicles at Rs.13,500	40,500
2. Shed accommodation at Gauhati	5,000
3. " " " Shillong	3,000
4. Passengers' waiting accommodation at Shillong	3,000
5. 2 drivers' quarters at Gauhati, at Rs.3,000 ...	6,000
6. 1 driver's " " Shillong	3,000
7. 25% of item 13 in the capital expenditure estimate of the tractor service	2,500
8. 50% of items 6, 7, 8, 9, 11, 12, 14, 15, 16, 19, 21, 22, 23 in same estimate	24,650
	Rs.87,650
Add 10% for contingencies	8,765
	Rs.96,415
Add cost for purchasing existing contractor's plant	60,000
	Rs.156,415
Deduct amount realized by selling same ...	30,000
	Rs.126,415

The vehicles should be engined with the motor usually used in a 3-ton car. This is to provide ample power on the long grades.

Sufficient vehicles have been allowed to provide for one making the journey up and one down, with one spare for cleaning and repair daily. In extraordinary press of traffic it will be quite possible to run one such vehicle the double journey in the day.

The cost of the motors has been taken as for a most expensive type of bus body. The most suitable type of body would be one seating 10 passengers in front, with a light roof over the seats, and a partition extending to the roof behind them, the sides being left open and fitted with waterproof curtains to keep out the rain when necessary.

The roof would be provided with a light rail, and made sufficiently strong to carry a few maunds of light luggage. Immediately in rear of the passengers' seats would be fitted a closed receptacle for mails, and in rear again would be a platform, with a light canvas tilt, for passengers' luggage, etc.

The total number of European passengers carried yearly is 3815·5. This, at 3 maunds each, including luggage = 11446·5 maunds = 26163·4 ton-miles.

The total weight of mails carried in the year, including those at present carried by bullock cart, is 4,347 maunds, or 9,936 ton-miles.

Thus the total load moved in the year is 36,099 ton-miles.

Taking the tare weight of one vehicle as 3 tons, the gross load moved is $3 \times 365 \times 64 \times 2 + 36{,}099$ ton-miles = 140,160 ton-miles.

Working Expenses on Carriage of Mails and European Passengers.

	Rs.
1. Annual cost of petrol, at Rs.1 2 0 per gallon, and ·03 gallons per gross ton-mile	5,949
2. Cost of lubricating oil, at ·1 pint per vehicle mile and Rs.3 per gallon	1,752
3. Cost of small stores, cotton waste, and cleaning materials, at Rs.60 a month	720
4. Cost of tyres, at 2¼ annas per vehicle-mile ...	6,570
5. Depreciation on 3 vehicles, at 20 % per annum, each costing Rs.13,500	8,100
6. Repairs, at 10 % on capital cost	4,050
7. 3 drivers' wages, at Rs.200 per month each ...	7,200
8. 3 cleaners' ,, ,, Rs.15 ,, ,, ...	540
9. Repairs to buildings, at 2 %	773
10. Add 25 % of items 11 and 15 in the estimate of working expenses of the tractor service	6,300
Add 50 % of items 7, 12, 16, 17, 18, 19, 20, 21 of same estimate	7,135
Add 10 % for contingencies	4,909
	Rs.53,998

Earnings on Carriage of Mails and European Passengers.

As regards earnings for one year :—

3815·5 passengers, at Rs.12 per head	45,786
1,908 maunds excess luggage, at Rs.5 per maund...	9,540
Sudsidy, at the existing rate of Rs.3,800 per month	45,600
For excess of mails over 6 maunds daily each way at present contract rates, approximately ...	2,500
	Rs.103,426

These results give a net profit on the service of Rs.49,426, or about 39 % on capital expenditure. And this is with a reduction of 25 % in the passenger fares, and 33 % for the rates for excess luggage below those now current. There is thus ample margin to provide for extra vehicles if found necessary to divide the daily mail into two despatches and receipts in the day, or to allow another spare vehicle in case of breakdown or other emergencies. Profit.

The allowance for workshop tools provides all small tools necessary for ordinary repairs. Any big work would have to be sent to the railway workshops.

This estimate illustrates the impossibility of laying down any fixed formula for the cost per ton-mile of mechanical road transport to suit all conditions. So much depends on whether the conditions of traffic allow a full load in either or both directions, whether the volume of traffic is regular throughout the year, whether the length of the route allows for a full day's work to be got out of each vehicle, whether the necessity of running to timetable requires the division of the daily traffic over two or more vehicles so as to fit in with timings of train or other services, etc.

This route appears to be an ideal one for making a thorough test of the suitability of mechanical road transport in India. The project was originally suggested by me to the authorities of the Eastern Bengal State Railway three years ago, when I happened to be in Shillong on leave, and I offered to collect traffic statistics and other particulars for it in my leave time, and I interviewed H.H. the Lieutenant-Governor of Assam regarding his willingness to allow the railway to undertake it.

The reply I received from the railway was sufficiently discouraging to make me regret having suggested it.

Having studied the matter in England last year, I suggested the scheme to H.H. the present Lieutenant-Governor of Assam, and also to the Chief Engineer of the province in November last.

They took the matter up warmly, and took measures to interest the railway board in it with a view to one of the railways concerned taking it up, with the extremely gratifying result that while concluding this report I have been officially asked by the railway board to prepare an estimate particularly dealing with the following points :—

1. Type of car to be adopted for passenger traffic.
2. " " " " " light goods and parcels.
3. " " " " " heavy goods traffic.
4. Number of vehicles required to convey existing traffic.
5. Total cost of installing the service, including staff quarters, workshops, and incident facilities required at Shillong and along the road.
6. Rates to be charged.
7. Probable return on capital invested on the basis of present traffic.

These points are all clearly dealt with in this paper. As regards rates, until the service has been working for a year, it would not be advisable to reduce rates below those calculated in this estimate, on the basis of the existing subsidy from Government remaining as it is at present. After one year's work it will be possible to see what effects the service has on cost of road repairs; and the rates, subsidy, etc., can be readjusted accordingly.

In conclusion, should any railway official wish to gain some knowledge of this subject during his leave in England, I would recommend the following:—

1. A course of practical work in repairs, driving, and diagnosis of complaints of motor vehicles, etc., at some large garage dealing with as many types of motors as possible, such as the Mechanical Transport Depôt of the Army Service Corps at Aldershot.
2. A study of current periodicals dealing with road-motor traction, such as *Motor Traction*, *The Commercial Motor*, newspapers, etc.
3. A study of periodical reports issued by the Mechanical Transport Committee of the War Office.
4. Visits to any commercial vehicle trials or exhibitions in England.
5. Visits to the garage of road-motor contractors, *e.g.*, Messrs. Thomas Tilling, of London, any English railway, etc.
6. Visits to a few of the best manufacturing works.

Personally I have experienced the greatest courtesy and hospitality from all manufacturers and others with whom I have come in contact in the course of my enquiries, notwithstanding that I had no orders for vehicles in my pocket or any prospect of obtaining any. I was particularly struck with the enthusiasm of everyone connected with the subject on its possibilities, and their courtesy in giving all information in their power.

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THE KHUSHALGARH BRIDGE.

BY

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THE KHUSHALGARH BRIDGE.

THE Khushalgarh Bridge, which was completed in 1907, was constructed so as to finally connect the main railway system of India, with the line of railway which runs from the west bank of the Indus to Kohat and Thal, at the foot of the Kurram Valley.

Up to the date of its completion, Khushalgarh was the terminus of the 5-foot 6-inch gauge railway which runs from Golra through Basal and Jand. The railway on to Kohat and Thal was a 2-foot 6-inch gauge, whilst the river itself was crossed by a bridge of boats for passengers—the goods being slung across by a cableway.

As the Indus rises to R.L. 800 in July and August—when melting snow and local rains combine to bring down the maximum floods—and falls to R.L. 745 in the cold weather, the new bridge is constructed in two spans, one 303 feet and the other 471 feet long. It carries on the top boom the 5-foot 6-inch gauge track, which has now been extended to Kohat; whilst on the bottom boom a cartroad has been constructed.

A description of the girders was given in *Engineering* in February, 1907, and from this the following short explanation has been compiled:—

Owing to the great depth of water, the 471-foot span was constructed on the cantilever principle, the design being also suited to meet the rock formation of the site. The east cantilever is formed by U 12, U 16, L 14, L 12 (*Plate* I.), counterbalanced by the 303-foot span, whilst M 31, U 30, U 26, and L′ 30 form the west cantilever, which is tied down by the weight of masonry above the anchorage M 31, and the girder, L 16, U 18, U 24, L 26, is suspended by the links U 16, L 16, U 26, L 26, from the noses U 16, U 26.

Holding-down bolts were also added at L o as a precaution, although neither during erection, nor under dead or live load, was there any actual uplift at this point.

Many members of the 303-foot span have had to undergo very large reversals of stress, *e.g.*, the stress in L 11, L 12, varied from 108 tons tension during erection, to 990 tons compression under full dead and live loads when the bridge was completed. Again, during erection the two halves of the 471-foot span were cantilever until the middle junction at U 21, L 21, was made, when L 16, U 18, U 24, L 26, became a girder supported at L 16 and L 26.

The top and bottom booms are 45 feet from centre to centre, and the girders themselves are 20 feet from centre to centre, giving a clear cartway of 16 feet. On the top boom the bridge takes the 5-foot 6-inch gauge—the Government of India standard B gauge of 1903. The cartroad is carried by steel troughs on cross girders at the panel points. The troughs are 2 ft. 8 ins. centre to centre, and the dead load on two troughs 26 ft. 2 ins. long is taken as 6·40 tons, the live and impact load as 24·10 tons, *i.e.*, 30·50 tons distributed over two troughs.

Plate I. gives a general elevation and plans. The 303 span can expand at L o and U o. The east cantilever and slung span (*i.e.*, L 16, U 18, U 24, L 26) can expand at U 16 and L 14. The west cantilever slides at L 30. The centre pier bearings can rock and rotate. Thus, referring to *Photo* 1, it is seen the pivot has movement in all directions. Further, the windward of these two centre-pier pivots can slide an inch in any direction, the diameter of BB being 5 ft. 6 ins. and the diameter of CC 5 ft. 8 ins. This is to prevent any wind stresses having a splitting action on the pier.

Another feature of the design is the movement given in a vertical plane to the parts U 16, U 21, L 21, L 15, and U 26, U 21, L 21, L 27, before the join was made at U 21, L 21, by means of wedges at U 16, U 26, L 15, and L 27. Diagrammatically the movements at U 16 and L 15 are as shown in the following sketch.

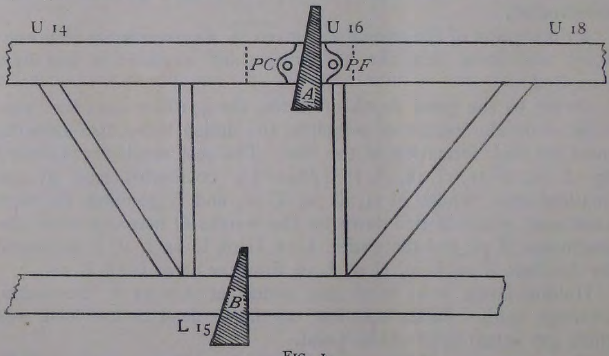


FIG. 1.

Suppose the pin and block PC is part of the moving cantilever U 16, U 18, while the pin and block PF is part of the fixed finished girder U 14, U 16; it is clear if A and B wedges are lowered the nose U 18 will fall, the top boom being in tension and the bottom in compression, which is the case until the middle join U 21, L 21, is made. These wedges and the brackets by which they were moved appear above the top and bottom chords in *Photo* 2. After the join

U 21, L 21, was made, all wedges and pins had of course to be removed.

Again it is to be observed that the chords U 16—U 18, U 24—U 26, L 14—L 16, L 26—U 28, might be removed and the slung girder L 16, U 18, U 24, L 26, would still be stable under certain conditions, the slung girder hanging directly on the links U 16, L 16, U 26, L 26.

For erection purposes very complete drawings were sent out from England, as were also stress diagrams and tables showing the stress in every member under all conditions, such as for the 303-foot span erected alone; for the east cantilever; immediately before joining up at U 21, L 21; wind; impact, etc., etc.

In addition to this the girders were all erected at Cargo Fleet, near Middlesbro', in the yard of the Tee Side Engineering Company (the makers), the joint marks fully stamped and painted, the schedule number of each piece painted on, and all parts painted different colours, before being put on board, according as they belonged to the anchor or to the east cantilever or west cantilever, etc.

The 303-foot span weighs 948 tons; the 471-foot span weighs 1,152 tons. Working stresses are 8 tons per square inch in tension and 6·8 tons in compression. For erection stresses these were increased to 12 tons tension and 10·2 tons compression.

The following is an account of work carried out at site in India:—

The manufacture of staging, cable towers—with erection of same—and erection of cables and of girders, was carried out departmentally, as no contractor would undertake the job at a reasonable figure.

Foundations.

All foundations are open and are on Upper Siwalik grey sandstone, a rock which unfortunately weathers very badly, and is more like compressed sand than ordinary sandstone.

Centre Pier.

During the cold weather of 1904–05 the foundations of the centre pier were put in, and the pier itself was built up 14 feet to R.L. 764 before the river began to rise in April, 1905. Work was resumed in September, and it was finished complete with bedstones and holding-down bolts for the centre pivots on March 15th, 1906. The details of construction are shown in *Plate* II.

The pier was built of face stones with concrete hearting, and this system requires constant supervision in order to secure a good joint between stone and concrete. The backs of stones must be chisel-dressed smooth, the concrete must be worked up against them with a special tool, and judicious grouting employed.

All work on the centre pier was carried out by means of a ramp, up which coolies carried the stones, mortar, and concrete. This ramp was built on the staging for the 303 span, the staging having been erected in 1905—1906, and dismantled again, as the girders had not arrived in time to erect before the 1906 floods.

East Abutment.

On the east abutment excavation began in June, 1905, the concrete in foundations on the 8th of August, 1905. Work was up to R.L. 823·80 on the 15th of November, 1905, and to 871 on the 15th of October, 1906.

Unlike the centre pier, which was all built in cement, the east abutment is built nearly throughout in kunker lime mortar of the following proportions:—Face stonework and through courses—15 lime: 15 sand: 100 cubic feet finished work all measured dry, and including wastage. Concrete—24 lime: 24 sand: 100 cubic feet finished work. It was found that the lime swelled when wetted, and so less dry lime mortar was required than dry cement mortar.

The proportions where cement mortar was used were—17 cement: 51 sand: 100 cubic feet concrete, or 22 cement: 44 sand: 100 cubic feet concrete. The kunker from which the lime was burnt was sent to Khushalgarh from Sargodha, the pieces being the size of a small pea. It was burnt in kilns $50' \times 6' \times 4'$ with wood and slack coal from Dundote; it was ground in a Carter's disintegrator and issued at once. The mixture of lime and sand was mixed wet in a steam-driven mortar mill for 20 minutes and used at once. It began to set in an hour, but did not set completely for six weeks. One lime to 1 sand gave results very nearly equal to 1 cement to 3 sand.

The sand used was 50 % fine white river sand and 50 % coarse sand, obtained from Jand and Campbellpore. The stone came from Serai Kala and Hasan Abdul. It is usually called nummulitic limestone, but some consider it to be of cretaceous origin, or even older. The courses are all 12 inches thick, stones varying from 12 cubic feet to 1 cubic foot. A cubic foot weighs 150 lbs.

West Abutment.

Details of both the east and west abutments are shown in *Plate* II. The latter was built throughout in the same way as the east abutment. During the cold weather, 1905—1906, materials were taken down on carts to the centre pier by road, there transhipped into boats, and mixed on the west bank. When the river rose in May, 1906, materials were sent across dry by the ropeways, and mixed on a platform on the west bank. In October, 1906, when the ropeways were required for girder erection, materials were taken across the boat bridge and up the west approach road by cart, mixed there and carried by a ramp to the top as work advanced. It may be of interest to note that a ramp to be used by men carrying large stones weighing 1,500 lbs., must not be steeper than $\frac{1}{2\frac{1}{2}}$, and that this gradient must not extend for more than 25 feet in length. A ramp is far more efficient than cranes and derricks for everything up to 1,800 lbs. per single piece—at any rate under the usual conditions prevalent at present in the Punjab.

Setting Out.

The centre pier was first built and the distance to the abutments were measured from it, thus avoiding any error in one span extending to the other span. On the centre pier a piece of iron $6'' \times 2''$ was embedded, and the exact centre marked on this iron by a small drilled hole. From this point the east and west spans of 303 feet and 471 feet were measured and similarly marked with a piece of iron in which a fine hole was drilled. The right angles were similarly marked.

Measuring was executed as follows:—With the two standard 10-foot rods sent from England any exact distance required was laid out to a temperature of 77°, on the coping of Khushalgarh East station platform, and marked with iron slabs and a drilled hole as on the piers and abutments. The wire of the measuring machine shown in *Plate* VI. was then adjusted to these marks on the platform coping, the machine was set up on the pier and abutment, and, after allowance for temperature had been made, the fine hole was drilled in the iron slab. The machine was finally checked again on the station platform.

Temperatures.

Observations for temperature were taken by ordinary air thermometers, wrapped round with wire of the same kind as used in the measuring machine. The wire of the machine was found by experience to take up the temperatures registered by the thermometers, and after one or two measurements and observations the machine gave great confidence. Over a span of 471 feet, differences of $\frac{1}{16}$ of an inch could be detected. 98° Fahr. was chosen as the normal temperature; as a matter of fact, during 1906 the minimum temperature registered was 38° and the maximum 134°. These temperatures were taken by putting the mercury bulb into a hole drilled 3 inches into a piece of rail hung on the girder and exposed to the sun.

Later experience proved that the bottom boom of the 303 girder never took up more than a through temperature of 110° Fahr., although the top boom at the same time showed as much as 130° Fahr. The cool snow water of the Indus no doubt was partly responsible for the low temperature of the bottom boom, but besides this it is also much more shaded than the top boom.

The abutments and anchorage were set out at the normal temperature, 98°.

The 303 Staging.

Plates VII. and VIII. show the staging on which the 303 span was erected. It is generally known as Deuchars staging, having been designed by Mr. G. Deuchars, the then engineer-in-chief of construction, N.W. Railway.

This staging, with floor and camber jacks, weighed 450 tons, and a weight of 700 tons was eventually distributed over it, the centre pier, and the east abutment before the 303-foot girder was able to support itself. It must be remembered that all weight was imposed immediately over trestles, and there was no load placed eccentrically to the trestles.

When this staging was put up for the second time in September, 1906, it was—excluding the floor—erected in a month, at a cost of

Rs.8,500, and dismantled in 19 days at a cost of Rs.4,500, which sum included carriage by cart for over a mile, and stacking.

The rails and sleepers of the vertical and raking legs, have since been used in the track. The tie-rods, junction rings, and bracings were all made up in the bridge workshop and tested before use.

It is worth noting that the longitudinal horizontal bracing rails of such a staging should be anchored into the abutment and pier.

The 60-Foot Cable Towers.

Plate V. and *Photo* 9 show the 60-foot cable towers which were made upon the same principle as the staging, the sleepers used being $14' \times 12'' \times 6''$ crossing sleepers, whereas in the staging the sleepers were the ordinary broad gauge, $9' \times 10'' \times 5''$.

It was found on dismantling these towers, that the standing 7-inch and 6-inch cables had cut into the hard kikar wood saddles to a depth of 1 inch.

The general scheme of the cableways is given in *Plate* III.

Erecting Plant.

The hoists of the erecting plant are shown in *Photo* 3, and were nominally able to lift 6 tons; boiler 10 H.P., steam pressure 100. The drum for the continuous hauling rope was converted from a cylinder to the shape shown in *Fig.* 2, by fixing six segments (cast in the Pindi shops) on to the cylindrical barrel with studs. The hauling drum and one hoisting drum were on the east bank, and one hoisting drum was on the west bank.

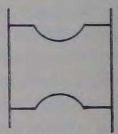


FIG. 2.

With this arrangement of two carriers, one running on each 6-inch rope, pieces up to 8 tons were easily handled, 4 tons only coming on to one rope. The piece, being handled, could also be put into any position in the plane of the ropes and carriers.

To transport materials for the masonry of the west abutment during the flood season of 1906, 7-inch ropes and a carrier were used. Including unloading, a trip could be made to the centre pier and back in 15 minutes; to the west abutment and back in 20 minutes. In the erection of the girders however more time was consumed while adjusting the piece through the last 10 feet and fixing it in position with service bolts, than by the actual transit. After the anchor span was completed, considerations of headway caused far more anxiety than the simple transit, because the ropes dipped so much in the centre that the load struck the top boom and jammed up against the hoisting tackle. It must be remembered that as a piece moved along, the hoisting ropes had to be simultaneously wound in or paid out, according to the direction the piece moved.

The anchorages were copied from *Figs.* 12 and 13, *Plate* I., *Military Engineering*, Part III., Bridging and the Use of Spars. Fourteen 75-FF 30-foot rails in a bunch were used for the cross beam (see *Plate* IV.). They were laid on 6 inches of concrete and filled in with concrete up to their highest level, so as to give an even bearing against the rock which was very weak in the east anchorage. The resistance of the anchorage was designed approximately equal to the combined breaking strength of the ropes, which was The Standing Cables and Anchorages.

$$\left.\begin{array}{l} 1-7''=225 \text{ tons} \\ 2-6''=280 \quad ,, \end{array}\right\} = 505 \text{ tons on each side.}$$

The ropes were fastened as in *Plate* IV. Screw couplings are awkward to use, and in order to tighten the ropes unloaded above a 40-foot dip, a locally made block and tackle for 4-inch steel rope (power of 5 with a 10-ton winch) was used. When the tension was taken by the tackle, the screw couplings could be adjusted. A permanent winch and tackle for each rope is recommended, and is the best system for similar conditions (given in Messrs. Bullivant's Catalogue). If there is only one winch and tackle for six ropes, screw couplings or some such device must be used also, because under the tensions used at Khushalgarh, fine adjustments in the dip of ropes cannot be made easily. Work was started with a dip of 40 feet unloaded, and ended with a 23-foot dip, so that the load should clear U 10 to U 20 (see *Plate* I.), and the wedge gear at U 16. On February 15th, at a temperature of about 60°, when a load of 7 tons of rails was being taken out (*i.e.*, 9 tons in all or $4\frac{1}{2}$ tons on each 6-inch rope after 2 tons are added for carrier tackle, etc.), the two 6-inch ropes dipped from 25 feet unloaded, to $43\frac{1}{2}$ feet when the load was in the centre of the span. With 10 tons of rails (=total 12 tons) the two 6-inch ropes dipped from 25 feet unloaded to 50 feet when the load was in the centre of the span. A factor of safety of 4, *i.e.*, a

$$\frac{\text{guaranteed breaking strength}}{4}\left(\text{in the case of 6-inch ropes, } \frac{140}{4} \text{ or } 35 \text{ tons}\right)$$

tension was adhered to as far as possible. Most of the heavy pieces weighed between 5 and 8 tons, and this weight the cableway could handle. The two pedestals of the west cantilever weighed 10 tons each; these were ferried across in boats, and hauled into position on a special rail ramp with special tackle.

The hoisting ropes—which were 2-inch circumference and guaranteed breaking strength 11·83 tons—were neverstrained beyond a factor of safety of 6. Nor was the 3-inch hauling rope, with a weight of 7·62 lbs. per fathom and guaranteed breaking strength 25·7 tons. All ropes were kept reeking in tallow and castor oil, and when taken down were as good as new. The 2-inch hoisting rope had lost $\frac{1}{8}$ inch to $\frac{1}{16}$ inch in circumference where most worn. All ropes were supplied by Messrs. Bullivant & Co. All joins in the ropes were made with clips, as shown in *Fig.* 3, and there was not a single instance of slipping, as long as the bolts were tightened periodically. It is an important point to tighten up such clips when the ropes are being stretched, as the sectional areas of the ropes are then at a minimum.

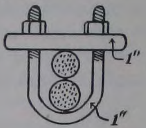


FIG. 3.

Erection.

The girders on arrival from England were stacked at a temporary loop, $1\frac{1}{2}$ miles away. At the bridge there was a loop and a dead end. The pieces were brought by B.G. train to the bridge; there unloaded by crane on to man-handled trollies, which ran underneath the centre of the cable tower, and which could be traversed right and left to a position immediately under the ropes. For the erection of the 303-foot span the traverser—which was very essential—was on the east abutment; for the 471-foot it was at U 10.

For the 303-foot span four camber jacks were used under each panel point of the lower boom. The bottom boom was all brought out (beginning from L 12 and working to L 0), and bolted and hydraulic riveted as far as possible with bottom wind laterals and cross girders. The verticals and diagonals up to the M joints were then brought out in any convenient order and service bolted, and finally the M to U parts, working from 0 to 12. The *Photos* 4, 5, 6 and 7 show the progress.

The riveting of the M joints proceeded simultaneously with the erection. The 471-foot span was not commenced until the riveting of the 303-foot span was practically completed. This was for the following reasons:—(i.), The hydraulic riveters blocked the clear way for the cables; (ii.), some alteration was found necessary in the structure of the carriers, and (iii.) it was thought advisable to rivet up any parts of the cantilevers as soon as they were erected, and this could not have been done if the riveters were busy on the 303-foot span.

In the 471-foot span, a length of bottom boom and bottom wind laterals was erected first, and then the remainder of a bay from the bottom upwards.

E.g., suppose the work advanced to A—B was put in and held up temporarily by a Weston pulley block C (*Fig.* 4). Then D was erected, then E, and another pulley block F before E was released from the cable carrier. After this the order was G, H, K. The Weston pulley blocks, as they give slight adjustments, were very efficient.

It was tried whether bottom chord pieces such as B could be left, being held simply by bolts and drifts at *o*, and it was found the end *p* hardly sagged at all, but with a pulley block C the exact camber could be kept without delay. A piece B could not be erected after E, or G, because when lowering B into position E or G would foul the hoisting ropes and tackle.

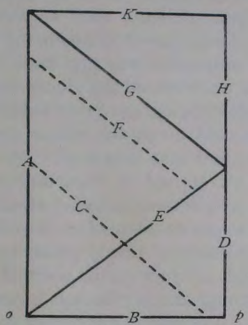


FIG. 4.

The 303-foot span was erected with a 3-inch camber + ½ inch allowance for settlement in the staging. The 471-foot span was laid out to levels shown in a diagram sent from England. This diagram gave the proper height of each point when the cantilevers were finished to U 16 and U 26, and also just before the final joint at 21 was made. When the two cantilevers met at 21, the west was 2 inches and the east 3½ inches too high, and the bottom booms were 1½ inches too close together, a position of affairs shown in *Photo* 8. By lowering the wedges the noses were brought down to the same level, and the bottom boom separated to the correct 3 inches. The north girder had to be cooled with a spray of water, owing to the sun after 2 p.m. being on it, while the south girder was in shade.

The closing pieces were put in as follows :—(i.), L 20, L 21 ; (ii.), L 20, M 21 ; (iii.), U 20, M 21 ; (iv.), U 20, U 21. The joints L 20, U 20, were riveted up first, and every preparation was made so that all the riveters could be concentrated on L 21 and U 21 when the opportunity came for riveting up these joints.

Further it was necessary to rivet U 21 at a falling temperature, as the bottom wedges at L 15 and L 27 were relieved of pressure as soon as L 16 to L 26 became a continuous boom in tension, and also as soon as U 21 was strong enough, the bottom wedges had to be lowered out of the way, so as to prevent any possibility of a rise in temperature making the bottom booms buckle. This buckling did actually occur on July 8th, before any rivets were put in at L 21, as the plates were butting against each other ; but a spray of water soon cooled the girders down and the kink disappeared. Similarly the top boom joint L 21 had to be riveted at a rising temperature, and 100° Fahr. was chosen at which the joints were to be made. At the actual time calculated for riveting up the bottom boom on July 8th, the temperature happened to be excessively high, but a providential storm cooled the air, and riveting began at 4 p.m., and continued with artificial lights until 11 p.m., temperature falling slowly all the time. To join the top boom, the temperature was not high enough on the 9th, and it was not until 12 noon on the 10th that the sun came out from behind the clouds and the necessary temperature was obtained, bringing the rivet holes opposite each other. A shout of "Allah" went up as the order was given for riveting, and by 7 p.m. the 261-foot span was slung.

The 303-foot span was started on December 3rd, 1906, and erected in 38 working days, which time included riveting both the bottom boom and a proportion of the M joints. Riveting was complete on March 19th. The erection of the 471-foot span began on March 15th, and was finished on July 15th, complete with floor plates, stringers, and everything except the ash screens. The best day's erection was 40 tons. The rate of erection of the 471 span depended on the rate of riveting each day. The erecting and riveting gangs were all from the Punjab. A Bombay contractor and Bombay mates were invited to see the work, but they all asked exorbitant rates.

The Hydraulic Riveting Plant.

The accumulator of the hydraulic riveting plant weighed 13 tons and had a stroke of 8 feet. The boiler was 8 H.P. with 100 lbs. working steam pressure. This was sufficient if all pipes and machines were tight, and allowed three machines to work at once. The installation of pump, accumulator, and machines was supplied by Messrs. Fielden & Platt, Atlas Works, Gloucester. A 12-H.P. boiler would have been better, as, when a machine was not quite tight but still not bad enough to remove for repairs, the fall of the accumulator was beyond the power of the 8-H.P. boiler to raise quickly enough for continuous working of all machines. The machines worked satisfactorily until the temperature of the water rose above 110° in them. One machine was used on the east bank to rivet gussets to members before sending them out on the carrier—which could be done when the combined weight of the member and gusset was not over 5 tons. For this machine the lead pipes were buried and the machine itself wrapped in wetted gunny, and this worked quite satisfactorily, even in June and July. The water used was pumped from the river, and passed through settlement tanks and filters before reaching the final tank. This tank was 12 feet above the pump so as to prevent air getting into the pipes.

The best day's record for a machine was 175 rivets. Each machine weighed $2\frac{1}{2}$ tons, and in many places the staging for the workmen had to be erected after the machine was in position; it was due to this that time was wasted. If such heavy machines are used, they require a special arrangement from which to hang them. At Khushalgarh there was not sufficient headway above the top boom for any such arrangement. Not only did the standing ropes foul the crane jibs which were used to suspend the machines, but there was also fear of an accident from the swishing hauling and hoisting ropes of the carriers. It is usual with cableways of this kind to have a button rope and plough to hold up the hoisting rope, but as the workshop at Khushalgarh was always pressed for time (the staging, carriers, tackles, cranes, hoisting and hauling engines, etc., etc., all being made or altered there), it was thought better to forego the button rope and its details, which would bring more work on to the shops. The water pressure at the machines was 1,500 lbs., which gave a 20-ton pressure on the snaps. The machines had a 6-foot gap.

Somewhat late in the day, after it was seen that the hydraulic riveters could not do the work as expeditiously as required, it was determined to employ pneumatic riveting plant. It proved to be most efficient. No. 80, 90, and 000 Boyer's hammers were used with air pressure 80 to 100 lbs. The maximum day's work of one hammer was 240 rivets, and in practice the holding up of the rivets regulates the capacity of a hammer. At Khushalgarh an average per hammer was 1,800 good rivets in the month, not counting bad rivets, which had to be cut out in the men's own time. Pneumatic Riveting.

It must be recognized too that the hammer must be opened and cleaned after five hours' work, that one native cannot stand the jar of a hammer for more than an hour continuously and that some method of holding up with light screw jacks is necessary. The ordinary hand holding-up dolly does not give tight rivets, and a well-heated rivet throughout the stem will have the tail in the holder-up so hot, that the first two or three knocks with the pneumatic hammer will knock down the tail $\frac{1}{8}$ inch; nor do pneumatic holders-up answer well in great heat. Many spare snap heads also are required for the hammers, and proper special steel for the snaps was not available.

At Khushalgarh, when work was in full swing, one lathe was entirely given up to making snaps. In pneumatic riveting the same length of shank in rivets was used as for hydraulic rivets; for hand riveting the shank had to be reduced.

The air compressor used was 16-inch cylinder, 24-inch stroke, and with 75 lbs. steam pressure gave 60 revolutions a minute, thus compressing 315 feet free air per minute. The lead pipes were 4-inch wrought iron with screw collar joints. In order to carry the air and hydraulic pipes across to the west abutment, a light suspension bridge was built, with three steel ropes. The bridge was designed to carry 10 workmen besides the pipes. On the first day after completion, all the workmen began to stream over this bridge at the luncheon hour, but were luckily caught in the act and stopped.

Two nets will be seen in the photos, which could be hauled to any position under the bay where work was in progress. These nets measured 60′ × 40′, and were made locally by the river boatmen of $\frac{1}{8}$-inch twine. They were supported by iron rings running on steel ropes.

To ensure against damage to the staging from fire, a 3-inch iron pipe was taken across the bridge, fitted at intervals with branch canvas hose pipes and nozzles. There was a good head of water, and special men were trained to man the nozzles and valves when the fire bell rang. There was also a tank of water on the east abutment, and four native water carriers always on duty. A special supervisor was told off to see that all riveting fires were out before the men left for lunch and in the evening, a most necessary precaution when working with native workmen in a district liable to sandstorms.

It should be noted that factors of safety for temporary work in India must in many cases be high, and the statement sometimes seen in print that for temporary work a lower factor of safety may be used than for permanent work, is one that should be carefully analyzed. For instance, such things as chains, hooks, shackles, revolving pins, etc., used for slinging and moving weights, though not in a permanent work, must have very high factors of safety. They are subjected to constant impulsive strains; they are used over and over again; they jam, and two or three coolies set to work with a large crowbar; and they are exposed to rain and sun.

Some pulleys and slinging links were sent out from England, of which the factor of safety was 4 when new. It should have been much higher. With steel wire ropes, considerations of their stretch generally come before that of their breaking strength, and steel ropes are liable to stretch with a factor of safety of less than 6. In riveting work requiring stagings, it must be carefully considered what stagings are to be used, their weight, and how many men will crowd on to them at one time.

Factors of safety again, in locally-made machines, depend on the quality of work your workmen can turn out.

A 10-ton (so catalogued) pulley block is guaranteed to have been tested to $12\frac{1}{2}$ tons. What is its working load? At Khushalgarh 4-power pulley blocks, catalogued at 5 tons guaranteed test, were tested with 4 tons, and the teeth all stripped. What sized chain should be used to suspend a 3-ton hydraulic riveting machine which remains suspended all day, is pulled up at night, and used in this way continually for four months, dangling 45 feet above the bottom boom of a precious girder?

It may be added that factors of safety dwindle very quickly when there is a 200 feet deep torrent below one, when a sandstorm may at any time come up without more than 15 minutes' warning, and when a machine is being handled which cannot be replaced except by indent on England—a process which takes so long usually that the job is finished before the machine arrives.

The following figures are given, as they may be of use to officers in India:—

STATEMENT SHOWING COST OF THE KHUSHALGARH BRIDGE AND APPROACHES.

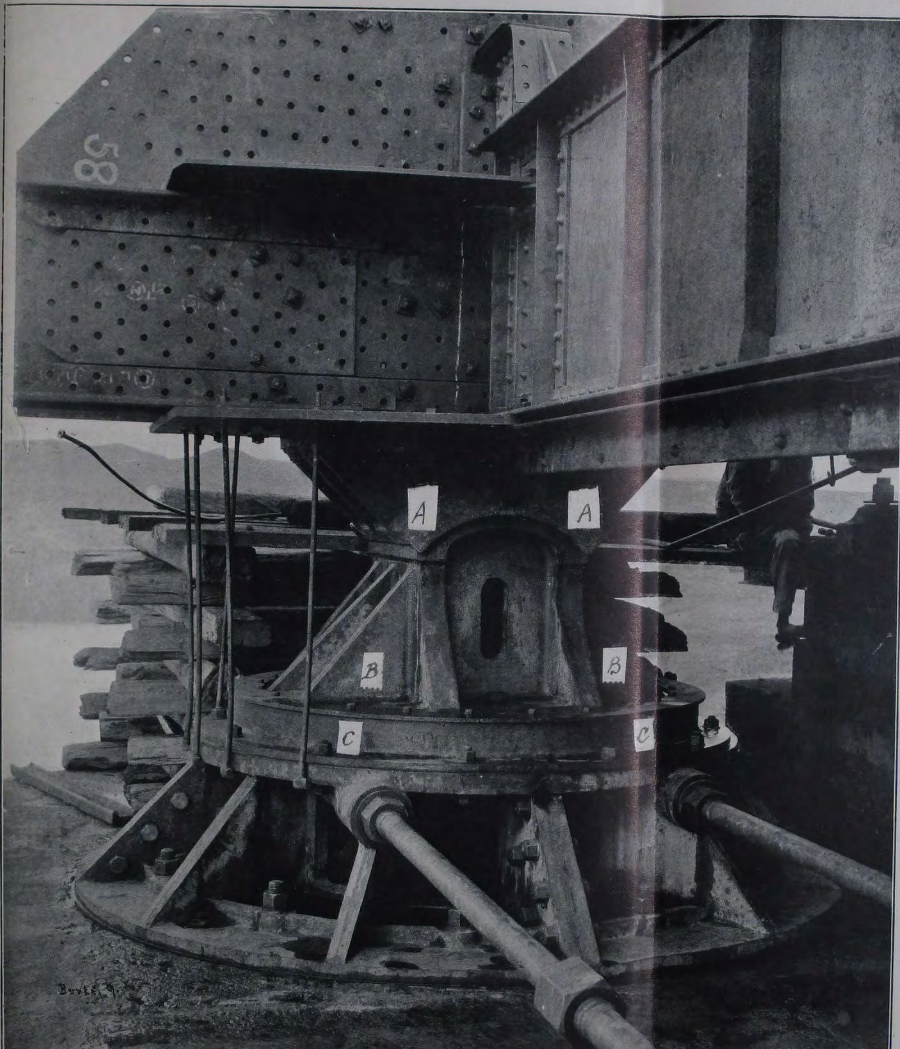
Head and Subhead of Accounts.	Particulars.	Rupees.	Remarks.
I. Preliminary Expenses.	*a*. Survey	3096	
	b. Plant	872	
	c. Establishment	2556	
	Total, I.	6524	
II. Land.	Land	7910	
III*a*. Earthwork.	a^1. Bank	21524	
	a^2. Cutting	151358	
	a^3. West Approach Road	10794	
	,, Retaining wall. Do.	6363	
	,, East Approach Road	6582	
	,, Retaining wall. Do.	3054	
	,, Retaining walls	63	
	a^4. Contingencies	1333	
	Total, III*a*.	201071	
IV*a*. Khushalgarh Bridge.	a^1. Excavation of founds.	9593	
	a^2. Cement	69822	
	a^3. Stone	161792	
	a^4. Ballast	91295	
	a^5. Kunker lime	85361	
	a^6. Other material and labour	68507	Masonry.
	a^7. Bedstones	2756	
	a^8. Girders	445262	English cost & sea freight.
	a^9. (1) Staging, labour	14052	Manufacture & erection in 1905
	a^9. (2) ,, material	57761*	
	a^9. (3) ,, dismantling	4932	
	,, Staging, re-dismantling	4582	
	a^9. (4) Staging, re-erection	8597	Erection in 1906
	a^9. (5) Sullivan's staging	662	
	a^{10}. (1) Cableway, labour	19790	Manufacture & erection & dismantling.
	a^{10}. (2) ,, material	40826*	
	a^{10}. (3) ,, labour in working	16403	Total weight transported, 6,000 tons.
	a^{10}. (4) Cableway, cost of water, fuel, etc	14589	
	a^{11}. (1) Loading girders at stacking ground, carriage to bridge, and unloading at bridge	14547	

* Credits from sales not shown.

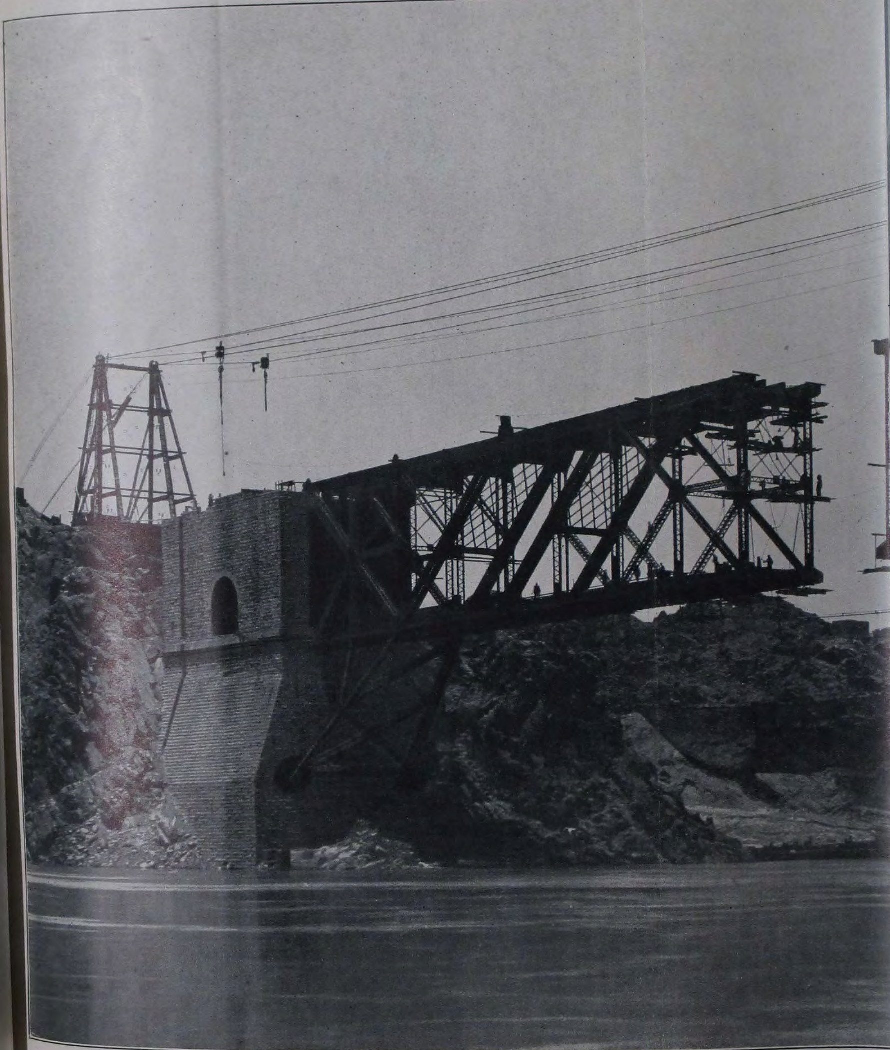
Head and Subhead of Accounts.	Particulars.	Rupees.	Remarks.
IV*a*. Khushalgarh Bridge (*cont.*).	a^{11}. (2) Assembling girder pieces from material trollies	60259	
	a^{12}. (1) Hand-riveting labour	24248	
	a^{12}. (2) Do. material	11052	
	a^{12}. (3) Do. tools	5435	
	a^{12}. (4) Riveting by hydraulic labour	8312	
	a^{12}. (5) Do. material	8929	
	a^{12}. (6) Do. plant and fixing	4539*	
	$a^{13}a$. Painting labour ...	5148	
	$a^{13}b$. ,, material...	6771	
	a^{14}. Masonry in parapet walls	—	
	a^{15}. (1) Defensible gates	—	
	a^{15}. (2) Masonry and foundation	—	
	a^{16}. Timber work in girders	9062	
	a^{17}. Petty tools........	11491*	
	a^{18}. ,, stores	2492	
	a^{19}. Contingencies	20136	
	$a^{20}a$. Riveting (pneumatic working)	13824	
	$a^{20}b$. Scraping	164	
	$a^{20}c$. Painting	308	
	a^{21}. Roadway across the bridge	1500	
	a^{22}. Suspension bridge ...	1035	
	Total, IV*a*.	1325834	
IV*b*. Minor Bridge.	IV*b*. Minor bridges and culverts	21324	
V. Fencing.	*a*. Fencing	424	
	b. Road crossing........	—	
	c. Mile and gradient posts	7	
	Total, V.	431	
VII*a*. Ballast.	Ballast collection	14808	
	,, spreading	1491	
	Total VII*a*.	16299	
VII*b*. P. Way.	b^1. P. way material........	127763	
	b^2. ,, labour........	2471	
	b^3. ,, maintenance ...	3139	
	Total, VII*b*.	133373	

* Credits from sales not shown.

PHOTO 1.



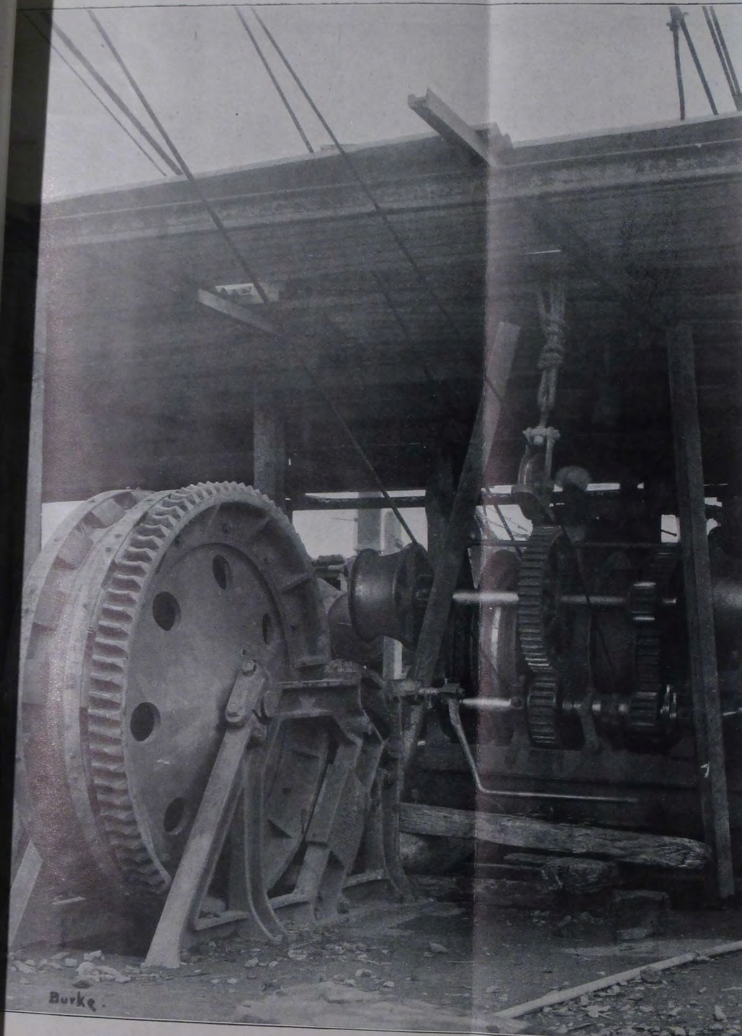
Centre Pier Bearings.
AA can rock on BB and BB can rotate in CC.



5th July, 1907.—Two Bays remaining. Suspension Bridge removed.

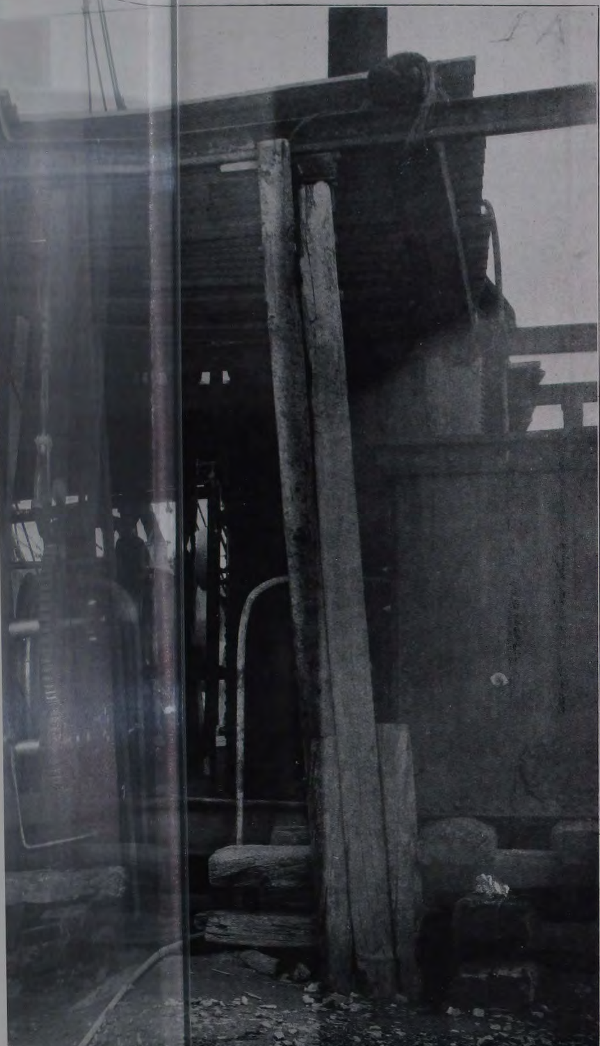
PHOTO 2.

A Pipe supported on a single rope.



The Hauling and Hoisting Drums. In the left foreground is a very powerful drum

PHOTO 3.



...left foreground is a very powerful drum, whi[ch] was discarded as being too slow.

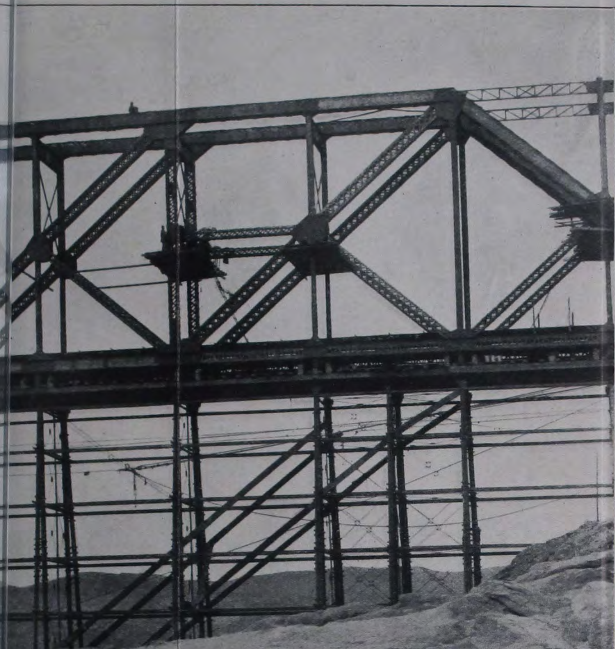
7th January 1907.

PHOTO 4.

ary, 07.

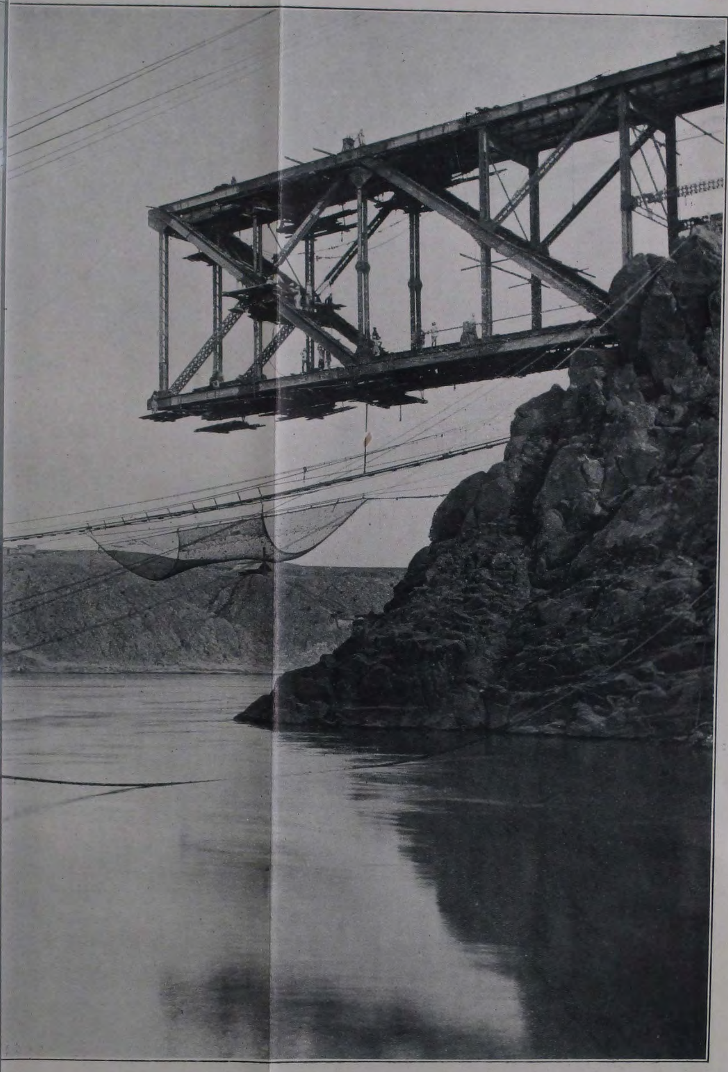
21st January, 1907.—Riveting Stagings

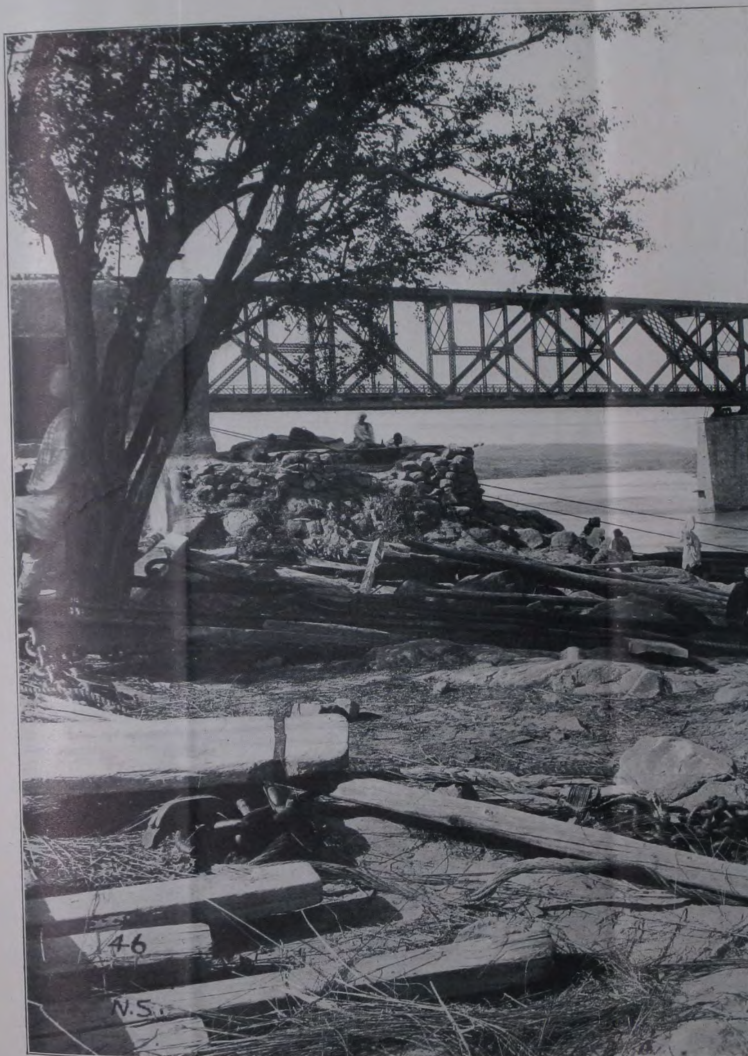
PHOTO 5.



ry, 1907.—Riveting Stagings M Joints.

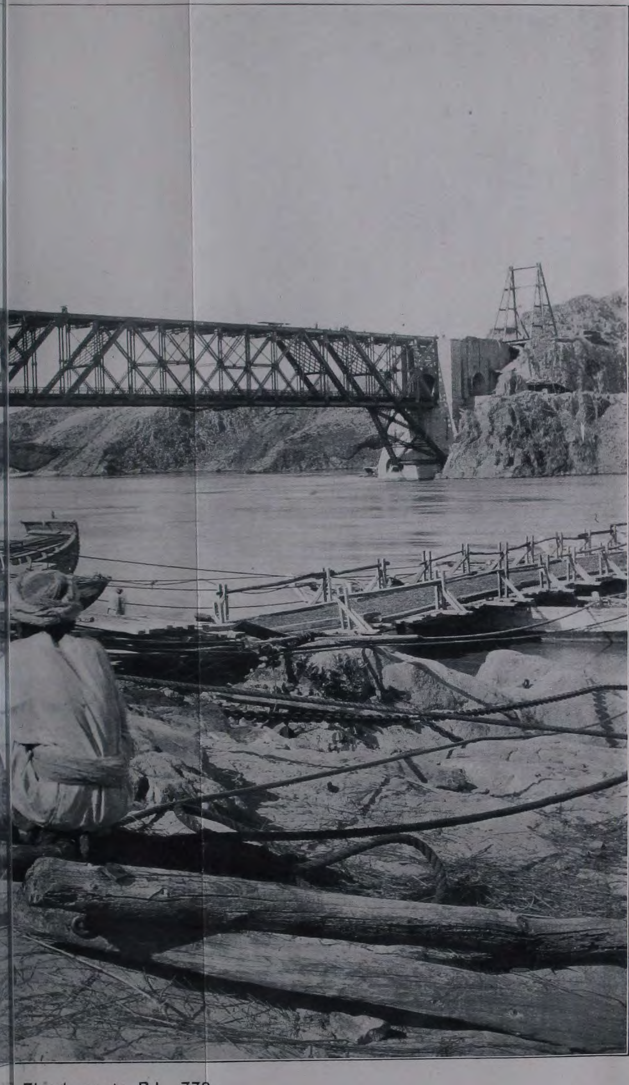
PHOTO 6.



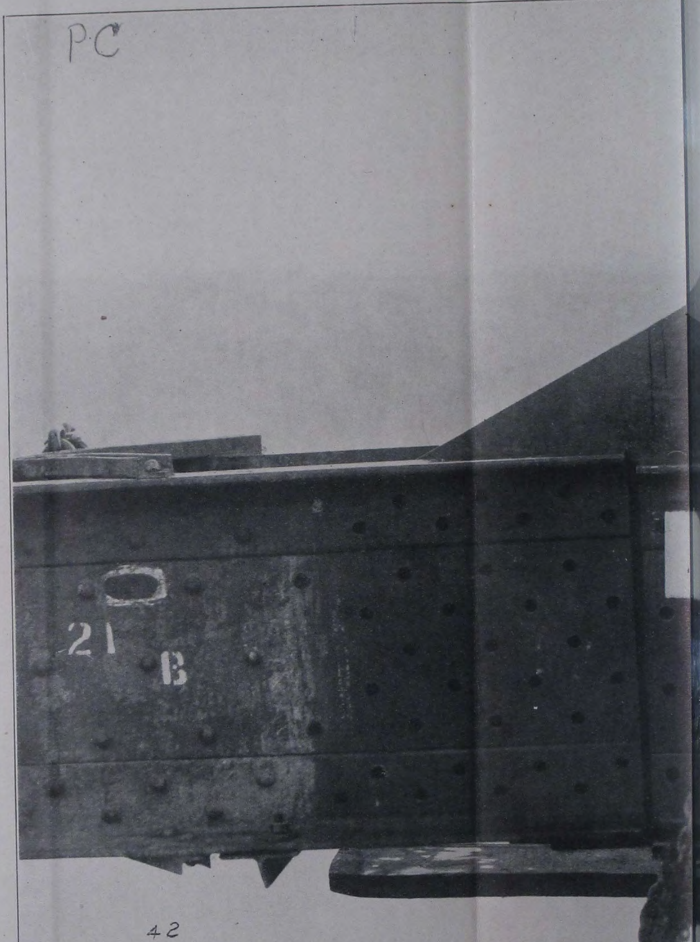


6th August, 1907.—Cables Dismantled.

PHOTO 7.

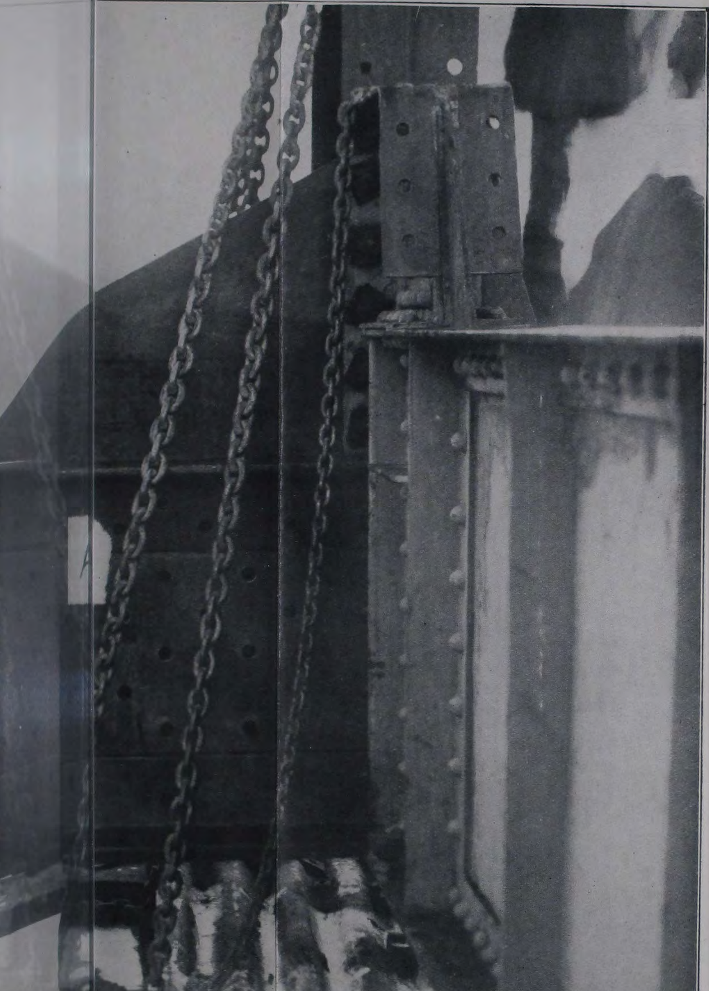


Flood, up to R.L. 779.



The Junction of the Bottom Chords at L 21 before final adjustments had b

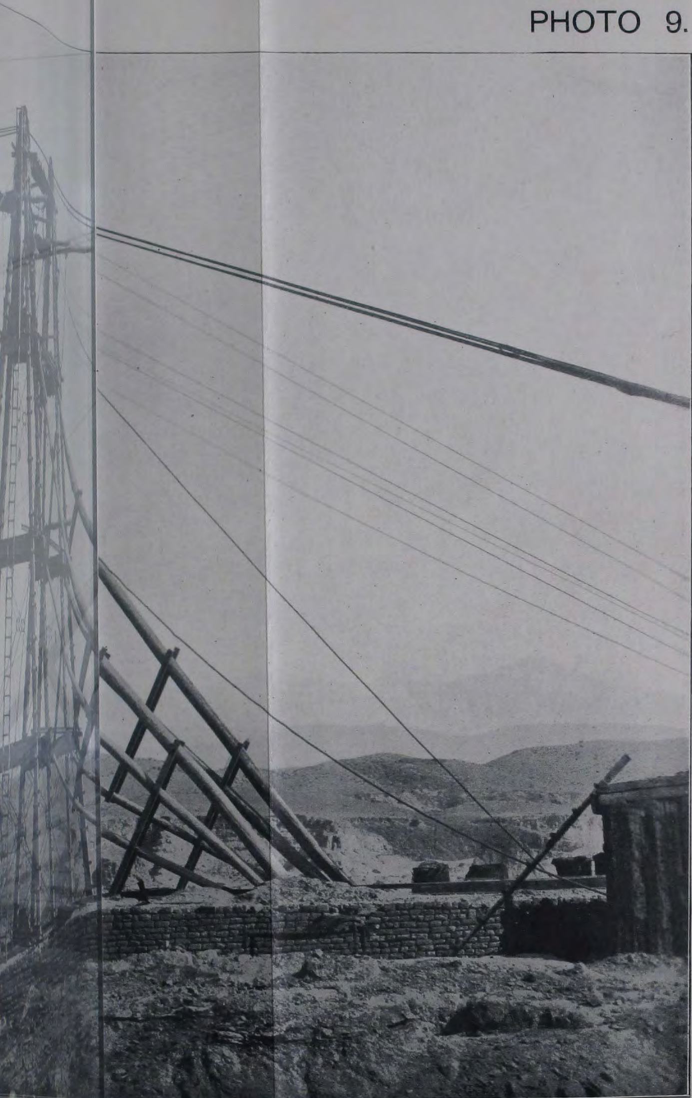
PHOTO 8.



...re final adjustments had be[en] made by the wedges. A has to drop 2 inches and B 3½ inches.

The East Cable Tower.

PHOTO 9.



The East Cable Tower

H.E. GÉNÉRAL DON JOSÉ MARVÁ

(Chef de la Section du Génie au Ministère de la Guerre, Membre de l'Academie des Sciences et de l'Institut de Reformes Sociales).

PROFESSIONAL PAPERS.—FOURTH SERIES.

VOL. II.—No. 4.

THE ENGINEER TROOPS IN THE CAMPAIGN OF MELILLA.

BY

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EDITOR'S NOTE.

THE following account of the work done by the Engineer troops in the Melilla Campaign, is from the pen of General Don José Marvá, himself one of the most distinguished Engineer officers in Spain. It originally appeared in the *Memorial de Ingenieros* and gives a good idea of the varied work done by the Spanish Engineers in Morocco.

The Editor of the *Memorial* has not only kindly consented to the present translation being published, but has also further assisted by generously lending, for reproduction, the original photo blocks of many of the illustrations.

ERRATA.

On *Plate* VI. (footnote), *for* "Alam brada" *read* "Alambrada."
On side note on *Plate* VII., *for* "Problado" *read* "Poblado."

THE ENGINEER TROOPS IN THE CAMPAIGN OF MELILLA.

WE do not pretend to make a detailed and reasoned exposition of the works executed up to the present by the Military Engineers at Melilla. This must be done at a later period when more complete data are available, but we cannot resist the desire of communicating to our comrades the information which we have received concerning the very interesting duties which the Engineers have performed under such varied conditions, including sapping, mining, telegraphy, signalling, radio-telegraphy, railways, ballooning and electric lighting. Many of these duties have been carried out under the fire of the enemy, and the Engineers have also taken a direct part in the fighting on numerous occasions.

I am not in possession of the operation diaries of the different Engineer units which have taken or are taking part in the campaign, but the continuous correspondence which I have maintained with the majority of the Engineer officers has given me data which I consider merit the attention of the readers of the *Memorial*.

BALLOONING AND ELECTRIC LIGHTING.

We will commence the relation of the works executed by the Engineers at Melilla, with an account of what has been done by the Balloon and Searchlight Companies. The reason of this preference is that it enables us to give to our readers a sketch of the country, positions, and places which have been the theatre of the operations. These interesting details are due to the observations made from the captive balloon and show the value of these observatories, raised to a height of 2,300′.

One balloon unit, consisting of two captive balloons (one spherical, the other of the German kite pattern) with the necessary equipment was sent to Melilla.

The very first ascents, made in the beginning of August, showed the importance of the balloon service. They discovered the positions occupied by the enemy on Mount Gurugú, the situation of his camps, the gullies in which he was hiding and from which he made his surprise attacks. Thanks to these observations the fire of the artillery was corrected, so that it was enabled effectively to search the enemy's positions. The ascents were continued during the first fortnight of August from the Hipódromo, Casa del Cabo Moreno, and Bocana de Mar Chica, and useful reconnaissances were made of the district north of Mount Gurugú, and of the country between the eastern slopes of that mountain, Mar Chica and Nador, as far as Zeluán. The furious easterly gale which broke loose on the 14th August made it necessary to deflate the balloon, and to postpone its transfer to la Restinga which had been fixed for that date.

During these ascents photographs were taken and sketches made which enabled many details of the country to be fixed which had previously been unknown, such as sites of villages and important hostile positions.

Sketches and Drawings made from the Balloon during the Earlier Ascents.—*Plates* I. to III. are the fruit of the observations made by Capts. Gordejuela and Herrera during these first ascents. The drawings give a perfect idea of the country between the Hipódromo, Nador and Mar Chica and have enabled the map shown in *Plate* I. to be prepared from the observations from the captive balloon made at an altitude of 2,150′. On it will be seen the direction of the two lines of rail belonging to the Riff Mines and North African Companies which started from the Hipódromo and led to the Second Blockhouse, and also the branch constructed by the former company to the Bocana de Mar Chica.

Peaks 1 and 3 of Mount Gurugú form the Barranco del Lobo, at the end of which the Lavadero Redoubt has been constructed.

The panorama made at a height of 2,150′ above the Hipódromo, and above the Casa del Cabo Moreno (*Plate* II.) shows well the position of peaks 1 and 3, the Barranco del Lobo, and the small hill 4 at the back of which the Moors had established one of their camps. Peaks 1, 3 and 4 with Lavadero were the scene of the operations of the 23rd to 27th July.

The panorama made from the balloon at the same altitude above la Bocana (*Plate* IV.) gives a perfect idea of the situation of the Atalayón and of Sidi Hamet, dominated by the eastern slopes of Mount Gurugú. Further off can be seen Zeluán, and still further away Mount Milon and the range of Beni-bu-Ifrur.

The Balloon at la Restinga and Nador.—At the end of August and the beginning of September the Balloon Company underwent a period of inaction in Melilla until on the 10th September it was transferred to la Restinga. This movement presented many difficulties, especially as regards the transport of the gas cylinders, which had to be effected in several journeys by boat *viâ* the Mar Chica.

At la Restinga the balloon was inflated and numerous reconnaissances were made up to the 26th September, on which day the Commander-in-Chief moved the company to Nador, the night being passed at the Second Blockhouse. This march of about 25 miles was performed by the balloon troops in 14 hours, during which the balloon was towed aloft.

On the 29th September, on account of the high easterly wind, it became necessary to deflate the balloon which had remained filled for 13 days.

The aerial observations made from la Restinga were interesting.

The panorama (*Plate* III.) taken from above the tongue of land which separates the Mediterannean from the Mar Chica, from a point situated between la Restinga and la Bocana, and the panorama from la Restinga, complete the view of that broken country in which the principal events of the campaign have been enacted.

The hills marked 8 were the scene of the heavy fighting on the 30th September. These hills, with 7 and those close to them, are the mountains of Beni-bu-Ifrur where are the iron ore deposits which the Spanish Riff Mining Company is trying to exploit.

The sketch (*Plate* V.), also drawn by Capt. Herrera from material obtained from observations made from the kite balloon Reina Victoria, gives a perfect idea of the Mar Chica from la Bocana to Ras Quiviana, including la Restinga and Zoco El-Arbaá. It includes Mount Gurugú with its eastern spurs, the high peaks 1 and 3 which form the famous Barranco del Lobo, the positions of Sidi Musa, Atalayón, and Sidi Hamet, Nador and the neighbouring mountains. Further away are the Kasba of Zeluán and the mountains of Beni-bu-Ifrur with Uixan, the course of the river Zeluán, with the marshes at its mouth, and Mount Tauima or Tanquemert, occupied by Orozco's Division in its advance on Nador. The railway from the old limits of Melilla towards Nador is also shown, and the most notable points are marked which have been the scenes of the attacks by the Moors on the convoys moving on Sidi Hamet, the Casa del Cabo Moreno, the First, Second, Third, Velarde and other Blockhouses, and the redoubts and other works constructed between Lavadero and the First Blockhouse.

On the 29th September the Balloon Company received orders to return to the vicinity of Melilla, but not before the occupation of Mount Gurugú had been observed from the balloon.

During the first days of October the company marched from Melilla to Nador, and on the 17th, under the protection of Aguilera's Brigade, it approached the Beni-bu-Ifrur country and was able to make a detailed reconnaissance of the ground, of the positions of the Moors, of the strength of the *harka* and the situation of the forces. The observation and correction of fire of the Schneider battery, with which the balloon was in telephonic connection, were made under perfect conditions, because the atmosphere was exceptionally clear. In consequence of this the fire of our artillery was exceedingly accurate and deadly.

Plates IX. to XIX. are reproductions of photographs taken from the balloon on different occasions.

It may be said that the country outside Melilla was quite unknown until the balloon lent its assistance.

The work of the Balloon Company has been very fatiguing, as during the day it had to attend to the balloon and at night work the searchlights used for lighting up the ground.

Searchlighting in the Field.—The C.R.E., Melilla, had two projectors. In June a 90-c.m. projector with a gasoline motor was sent to Melilla from the Engineer Park at Guadalajara.

On the 6th August three searchlights were working at Melilla, one from the fortress itself, one at Camellos, and the third at the Hipódromo. The light at Camellos illuminated perfectly the valley of the Rio de Oro, and the nearest spurs of Mount Gurugú.

In view of the good results obtained with these projectors four more were sent from the Balearic Islands.

During the first fortnight of September a 60-c.m. projector was working at la Restinga with a gasoline motor.

From the beginning of October the searchlights were distributed as follows :—

At Camellos, a 90-c.m. projector for the purpose of illuminating the valley of the Rio de Oro and Frejana in rear of the Zoco del Had (Sotomayor) position.

At the Alcazaba of Zeluán, a 60-c.m. projector.

At the advanced position of Kalb-el-Tor, a small oxy-acetylene, 40-c.m. projector, on the Barbier system, which had been sent from the Peninsula.

At Mount Tauimar, a similar light, intended to illuminate the plain of Zeluán.

At Nador, another, at the wish of General Orozco who occupied this position. It was also used to assist in unloading cargo at night.

There was also a projector at Beni-Ensar (Aid-Aixa).

The officers and men of the Telegraph Company occasionally assisted their comrades of the Balloon Company in working the lights at night.

FORTIFICATION WORK.

From the 9th July to the Beginning of August.—Hostilities broke out on the 9th July when General Marina pursued and punished the Moors who had attacked the workmen on the mining railway of the North African Company, and captured the heights close to the road which, starting from the boundaries of our territory not far from the Hipódromo, passes by the Casa del Cabo Moreno on its way to Nador, at the foot of the eastern spurs of Mount Gurugú and between the latter and the Atalayón.

The positions occupied by the gallant garrison of Melilla were as follows :—The Atalayón on the Mar Chica ; the Second Blockhouse on the railway ; Sidi Musa and Sidi Hamet el Hach, small hills at the foot of the spurs of Mount Gurugú. With the exception of the Atalayón all these positions are dominated at very short range by the ridges and gullies of Gurugú, so that their defensive capabilities are bad.

The Engineer troops of the fortress had to execute the works of defence in difficult ground and often under the enemy's fire, which occasioned sensible losses amongst the officers and men. These sappers, with those of the 4th Regiment who have constantly occupied dangerous positions whilst throwing up entrenchments and preparing camping grounds, displayed excellent discipline and admirable coolness. They had alternately to fight and to work, constantly to lay down the pick and seize the rifle, playing an honourable double *rôle* such as has fallen to all the Engineer troops during the course of the operations.

Thus we see in the attacks directed by the Moors against the positions of Sidi Hamet, before the 23rd July, that the sappers of the 4th Regiment distinguished themselves by their fire discipline. They only used five rounds per sapper and three per telegraphist during a very hard action. On several occasions Lieut. Beigbeder's sappers were employed by the commander of the detachment at the Atalayón in the night outpost line.

The works executed at the Second Blockhouse may be quoted as showing the dangerous nature of the work on which the Engineers were employed. Even after the works had been completed the least carelessness on the part of the garrison was paid for by numerous losses, so we can judge how exposed the sappers were whilst throwing up the entrenchments in the open under the direction of their officers, who did not consult their own personal safety.

The sappers of the 2nd Regiment who belonged to the Madrid Light Infantry Brigade had little time given them for rest on their arrival at Melilla on the 23rd July. They disembarked at 3 p.m. and one hour later were led by Major Padilla, Division Officer Melilla, to the Lavadero, where they fortified it and worked and fought all the evening and part of the night under the fire of the enemy without having any time for food.

General Marina praised their bearing and added that he understood and appreciated the hard task that had been set them, but the necessities of the situation required it.

During the night the sappers remained in the position without leaving it for an instant, being supported by two companies of the Barbastro Regiment, commanded by Colonel Aranda, who at 2.30 a.m. ordered the Engineer company to retire to the Hipódromo so that the men might get a meal. On arriving at this place, however, General Marina ordered Capt. Cueto's company to return to the position and to act as guides to two more companies of the Barbastro Regiment which were being sent up as a reinforcement. The General again praised the bearing of these troops in spite of the excessive fatigue to which they had been subjected.

The company remained in the same position throughout the 24th and 25th, working and fighting both day and night and performing all kinds of duties. Their fatigue became so great that many men fell asleep, rifle in hand, during the firing.

This company constructed two redoubts in front of the Lavaderos to defend the approaches from the Barranco del Lobo. These works were provided with trenches for fire standing and with wire entanglements. They were soon afterwards joined together, so as to form a single redoubt and thus to economize the garrison. We shall later on give a description of the redoubt as finally built.

On the 27th July no Engineers took part in the engagement at the Barranco del Lobo. The sapper company of the 2nd Regiment (Capt. Cueto) moved out from the Hipódromo to repair 200 yards of road. After this work was completed, in conjunction with two companies of the Melilla Regiment under Colonel Axo, they occupied the Casa del Cabo Moreno, from which they witnessed the light infantry action, encouraging the men with their cheers and finally retiring with the infantry to the Hipódromo without being engaged.

At the Hipódromo and other places the sappers of the 2nd Regiment also constructed magazines, with boarded roofs covered with earth, for the infantry and artillery ammunition.

The men of the 4th Regiment and of the Fortress Company continued their fortification work during the latter part of July and the beginning of August so as to improve the defences of Sidi Musa, Sidi Hamet and the Second Blockhouse. They built the Velarde Blockhouse with the object of flanking Sidi Musa and protecting the railway. This blockhouse is **Z** shaped in plan and has two tiers of fire, the lower one, 6′ from the ground, the guard bed being used as a banquette, and the upper one open, with a sandbag parapet.

The crest line is 130 yards long and the work was completed in two days. It consisted of a timber stockade with beams to carry the upper story and boarded walls, the latter being covered with steel plates in the upper part. The passive defence was completed by means of sandbags in the top tier and rocks in the lower tier. A wire entanglement placed at a short distance from the blockhouse served as an obstacle to attack and favoured the effect of the fire of the defence which was directed from a horizontal loophole running round the lower story and from the parapet of the upper story.

The other blockhouse, made of rails, was built between the Velarde and First Blockhouses, on a slight undulation of the ground. The following are its principal features :—Plan, square, 26′ side ; two tiers of fire, the guard bed serving as a banquette for the lower one ; upper tier in the central lantern which is blinded by steel plates ; earth parapet as high as the loopholes of the lower story, the upper part formed by a double thickness of rails, held between two timbers at each corner; tunneled entrance; wire entanglements and mines.

August and September.—At the beginning of August a line of entrenchments was planned for the purpose of protecting the exterior suburbs of the fortress from a *coup de main*. It started from Triana and the bank of the Rio de Oro and enclosed the Santiago Barracks and the forts to the west of the fortress. It consisted of sections of trench, supported by the forts and covered by a wire entanglement.

The 2nd Sapper Company of the 2nd Regiment, the Fortress Company and some others, were engaged on this work during the month. They also completed the Lavadero Redoubt which was the most advanced work on the side of the Barranco del Lobo, and which played a very important part until the occupation of Ain Aisa on Mount Gurugú. This position, astride the above-named and other gorges, gave complete security to the line Hipódromo-Second Blockhouse.

Lavadero Redoubt.—Pentagonal in plan, with unequal sides (see *Plate* XX.). Faces *ab*, *bc*, respectively 72′ and 118′ long, have for purposes of defilade a higher parapet (5′) than the others, and are provided with an interior trench which extends round the whole perimeter of the redoubt. The employment of stone in the parapets and traverses permits of their being given practically vertical interior slopes, so that the interior is well defiladed.

The parapet of faces *ed*, *de* (118′ and 56′) is lower (4′), and does not require a banquet. The gorge *ae* is an ordinary trench for fire standing and the interior space close to it is defiladed by the parados and traverses 12, 13, 14, 15 and 16, the profile of which is seen at PQ, RS, YZ, and VT. The work is surrounded at a short distance by a barbed wire entanglement with three rows of stanchions.

Shelters have been constructed in the parados 13 and 15 (see Sections YZ and OV).

There is nothing novel about the work, but it is very well applied to the ground and the materials have been well selected.

On the 12th August at 1 p.m. orders were given for the immediate construction, at the channel into the Mar Chica, of a work to hold 1 officer and 50 men, who were to be stationed there that night in order to guard the dredging plant which had just arrived from Malaga. The order was given to the sappers who were working at the Hipódromo 4½ miles away, and they at once proceeded to the channel. At 8 p.m. the work was completed, and both Colonel Aguilar and Capt. Cueto received the thanks of the General Staff for the rapidity and precision with which they had carried out the duty.

Fresh wire entanglements were constructed, and the parapets of the advanced positions and of the Second Blockhouse were strengthened. These works were constantly under the fire of the Riff marksmen at a range of 200 to 300 yards, which necessitated the employment of mantlets of iron plates to cover the sappers whilst working outside the trenches.

On the 22nd August the blockhouse on the railway was completed, and the Casa del Cabo Moreno was being put in a state of defence. On the conclusion of these works, on the 26th August, the fortress engineers commenced the construction of portable blockhouses which could be erected at any selected points.

One section of the 2nd Sapper Company of the 2nd Regiment started for la Restinga on the 24th August and arrived at the Zoco-el-Arbaá on the 25th, a place where ruins of an old Moorish market exist. It proceeded at once with the construction of trenches in front of the position, close to Mar Chica. For this purpose it carried out several demolitions, built dry rubble walls, and, amongst other works, constructed in two days four gun emplacements, each capable to holding two guns or even four in case of necessity. It placed a wire entanglement 1,300 yards long, cleared the field of fire, and constructed a large shelter for the transport animals of the column, which could be used as a redoubt if required.

Other works constructed by the sappers of the 2nd Regiment increased the defensive value of the old Zoco-el-Arbaá, amongst others a lunette in which some old walls were used as revetments, and biscuit boxes filled with stones were employed as traverses so as to gain horizontal space and save time.

These works had as their object to enable the place to be defended by a small garrison, so that the main body of General Orozco's Division could continue its operations towards Tauima and Nador and move along the south shore of the Mar Chica.

The operations, which commenced on the 20th September with the glorious action of Taxdirt on the Tres Forcas Peninsula, gave rise to fresh work for our sappers.

From the 20th September onwards.—The Campo de Gibraltar Brigade started early in the morning of the 20th September with Tovar's Division, and after separating themselves a little from the remainder of the troops, took the village of Taxdirt as their objective.

Capt. Arana's company of sappers marched with the vanguard of the column.

After having crossed a difficult ravine and whilst it was advancing on the hill just to the south of Taxdirt, so as to protect that position, fire was opened on the column at 10.30 a.m.

The sapper company took part in the engagement and acted as the escort of the artillery, relieving a company of the Chiclana Light Infantry Regiment.

The whole of the brigade took part in this glorious and hard-fought action against a brave and numerous enemy.

Capt. Arana, Lieut. Aguilar and Sergt. Berrocal of the Engineers specially distinguished themselves.

After the battle, the sappers prepared the bivouacs and entrenchments, and defended the bivouac of the headquarters of the division against a surprise attack which the Moors made during the early hours of the night with the object of surrounding our extreme right, formed by the Talavera Battalion.

The telegraphists assisted the sappers in the works of protection, the construction of trenches, and the arrangement of the bivouac.

The sappers of Alfau's Brigade of Tovar's Division were actively employed on this day. The camp of Tafart was placed in a state of defence after 14 hours of work by Lieut. Alberca and 50 men of the 2nd Regiment, who made use of the walls of the Moorish enclosures which they found there. In case the garrison were to be reduced later on, an interior retrenchment of stronger profile was provided, suitable for a force of one company.

The remainder of the company of the 2nd Regiment was with General Alfau at Jeuriart, where it built a redoubt.

The sappers of Sotomayor's Division, belonging to the 5th Regiment under Major Ugarte were present on the 22nd September at the occupation of the Zoco-el-Had of Benisicar. The Zoco is situated in an excellent position on a wide table-land of horseshoe form several kilometres in extent which here dominates the valleys of Frajana and the Rio de Oro, and from whence the ravines on the western flank of Mount Gurugú can be searched by artillery fire.

The sappers of the 5th Regiment rapidly entrenched the position for a length of 770 yards and on the following day commenced the construction of the four redoubts which were considered necessary to ensure possession of the table-land.

The following days were devoted to perfecting and increasing the defensive value of the trenches, erecting wire entanglements and finishing the redoubts. Early in October other communication trenches were made and more wire entanglements, and a portable wooden blockhouse of two stories, which had been made in Melilla, was erected.

At the same time the sappers of the 5th Regiment constructed defensive works at the camp of Hayara-Muna, a position half-way between the Zoco-el-Had of Benisicar and Melilla, which was 1,100 yards long by 550 yards wide and was occupied by the headquarters and main body of the division.

The communications with the Zoco were difficult. On the day of the advance the artillery got their guns up to the Zoco with much difficulty, one by one, four pairs of horses being hooked in. With the aid of the works carried out by the sappers all kinds of vehicles were able to move with facility.

On the 10th October the sappers arranged to transform the field-works into others of a semi-permanent character which would require a smaller garrison and would permit of the troops of the division being used for further operations.

We owe to Major Ugarte the sketch of the important position of Zoco-el-Had or Zoco of Benisicar occupied by Sotomayor's Division (see *Plate* VI.).

The high plateau which separates the Rio de Oro from the head of the valley of Frajana has been entrenched in the manner shown in the sketch, the defences being strengthened by a battery, one redoubt for three companies and another redoubt for one company.

The plateau of the Zoco extends so as to form a small divide between the Frajana and Zadsedia-Namen streams which flow to the right of the Rio de Oro. The headquarters of Sotomayor's Division were established on the long and narrow plateau of this small divide, at a place called Hayara-Muna, and various works of defence (two company redoubts) were provided. The western ravines of Mount Gurugú can be searched at a range of about 3 miles by artillery posted on the plateau.

The position of the telegraph and signalling stations and lines established by the telegraphists of the 5th Regiment can be seen on the sketch, as well as the road made by the sappers as a line of communication between Melilla and the Zoco.

Plate VII. gives a panoramic view of the whole horizon, taken from the camp of Hayara-Muna, starting from due north (N. 0°) and passing through east and south to 360°.*

It also has been drawn by Major Ugarte and gives a perfect idea of the ground.

During the end of September and the beginning of October, Capt. Ortega's sappers of Orozco's Division took part in the operations which resulted in the occupation of Mount Tauima, Nador and Alcazaba de Zeluán. They always marched with the vanguard of the columns, took part in the fighting, and constructed defences at Nador and on the hills and in the orchards near it, as well as a pier in the Mar Chica.

The sappers of the 3rd Regiment moved from Nador with Tovar's Division against Zeluán. They were the first to penetrate into the Alcazaba of that name so as to reconnoitre the interior and prevent a surprise. In the vigorous offensive reconnaissance on the 30th September in the mountains of Beni-bu-Ifrur, Capt. Arana's sappers, leaving their pack equipment behind, fought in the front line with the advanced companies of the Cataluña Regiment, and later on acted as escort to the battery. These same troops organized the defences of the Alcazaba of Zeluán (see *Plate* VIII.).

The Alcazaba is of large area, and almost rectangular in plan, the sides being 230 by 204 yards. Large flanking tambours were constructed at the angles with loopholes close to the ground. The

* In order not to make the plate too large the sketch has been divided into two parts; the lower part should be placed on the right of the upper part. The observer is supposed to be stationed at the camp of Hayara-Muna.

defence was concentrated in these works, as a very large garrison would have been required to man the whole perimeter of the walls, which, being very high, would also have had much dead ground in front of them. They are regular redoubts, one being for two companies, the other for one company.

The heights were also entrenched, in the form of a horseshoe, from Bu-guen-Zein to the north-east of Zeluán. Three company redoubts, three section redoubts, batteries, wire entanglements and fougasses were constructed.

A part of Capt. Cueto's company (2nd Regiment) assisted in making the defensive works at Zeluán and the neighbouring positions. One section was at Jeussalt (Tres Forcas) completing the defences of the position for a garrison of two companies. The site chosen was close to the Cala de los Pájaros.

OTHER WORKS.

Works on Mount Gurugú.—At the beginning of October the Melilla Company of sappers was engaged in strengthening the positions occupied by Colonel Primo de Riveira on Mount Gurugú, and constructed, under the direction of Lieut. Carcaño, three redoubts, one for two companies and one mountain battery, and two others for garrisons of two and one section respectively.

The redoubt is an irregular polygon in plan, this trace being required both by the nature of the ground occupied, and by that of the surrounding country which had to be swept by fire, and from which the interior of the work had to be defiladed (see *Plate* XXI.). The profiles shown in *Figs.* 1 to 3 and the undulating surface of the site give an idea of the ground.

All the parapets, traverses, and parados are of stone, topped with sandbags, and their trace and height are such as the exigencies of defilade require. A wire entanglement with four rows of posts serves as an obstacle.

The work is perfectly adapted to the ground and is well defiladed from the heights that command it.

Two sections of the 4th Regiment are in the Second Blockhouse and are clearing the cuttings of the two lines of railway (Riff Mines and North Africa) which were occupied by the transport animals. Another section is working on the details of the Sidi-Hamet defences and will afterwards go to the Lavadero to make a redoubt there, so that the position may be defended by a single section.

At Tauriart (Tres Forcas Peninsula) Lieut. Moreno Lázaro has constructed defensive works well adapted to the ground.

The sappers of the 5th Regiment are continuing the works at the Zoco of Benisicar, and are increasing them and considerably strengthening their profile.

MINING WORK.

Mines and Fougasses.—It would not be possible for sappers to neglect the use of explosives which from time immemorial has been one of their technical functions and they have accordingly utilized them on as many occasions as the nature of the war and of the enemy has allowed.

Apart from the charges used for blowing up rocks and obstacles encountered by the sappers both within and without the territories of Melilla whilst engaged in roadmaking, and for the destruction of obstacles whilst clearing the field of fire in all the positions occupied by our troops, explosives have been employed in the demolitions of *duars* and villages. This action has been necessary on several occasions as a just punishment for the hostile and traitorous conduct of their inhabitants (*e.g.*, Quebdana, Beni-Sicar, Nador).

In order to increase the defensive value of the positions the sappers of the 2nd and 3rd Regiments have placed mines and fougasses in front of the wire entanglement covering the fortress of Melilla, the camp of the Zoco-del-Arbaá and at other points.

Automatic Mines.—The value of automatic mines could easily be foreseen from the earliest moments of the campaign. The Moors, acquainted with the smallest details of the ground, and brave to excess, made use of the darkness of the night to descend from the ravines of Mount Gurugú and invade the country between the positions echelonned from the Hipódromo to Sidi-Hamet and the Atalayón.

The employment to the fullest possible extent of both automatic and controlled mines was thus clearly indicated.

Events have proved the great material and moral effect of these devices, and the value, not to say necessity, of applying on a large scale those measures which the skill of the miner and the teachings of recent wars, more especially of the Anglo-Boer War, show to be effective, particularly in face of an enemy such as the Riff who is inclined constantly to harass both by day and night the camps and positions occupied by the troops. In such cases explosives should be used to a very great extent.

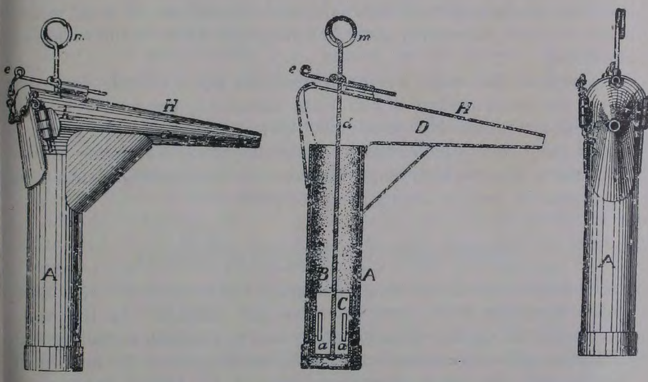
Some practical examples will show this more in detail.

While the sapper company of the 3rd Regiment was constructing works at the Casa del Cabo Moreno work was interrupted at night, and resumed on the following day. Having observed the presence of Moors in the neighbourhood of the works, Capt. Arana and Lieut. Aguilar placed an automatic mine close to them. It consisted of a cylindrical excavation, at the bottom of which 3 kilogrammes of picrinite were placed, with a detonator fired by a friction tube, similar to that employed by the artillery. The excavation was filled with stones, and above it was placed a Mauser ammunition box also full of stones, to the bottom of which was attached a wire communicating with the friction tube. On lifting the box the strain on the wire fired the friction tube and exploded the charge.

At 11 p.m. on the night of the 22nd August a loud detonation announced the working of the automatic mine, the effect of which could be seen next morning from the dismembered corpses of the Moors which lay around it.

Another automatic mine placed between Sidi-Hamet and the Second Blockhouse met with equal success; and in view of the results obtained, Major Catalá placed others in the wells and in the position intermediate between the Hach and the Second Blockhouse. The Moors, however, did not again approach them, as they were warned by experience and perhaps informed of the existence of the mines. As a consequence, no more damage was done to the railway and two boxes of provisions which had been left during the night by the canteen steward of the Atalayón at the foot of that hill were not touched.

The ingenuity of our officers was much exercised in preparing disagreeable surprises for the Riffs. The service friction tubes require too great a tractive force to explode them and consequently a friction tube was improvised which is shown in the accompanying figures—



This friction tube consists of a small conical tube full of powder, at the end of which is a cap of fulminate to detonate the explosive. At right angles to the conical tube there is another cylindrical one lined with sandpaper, within which there moves a small plunger provided with slots in which are fixed a few match-heads. A wire connected with the plunger leads to the outside of the tube and ends in a small ring, to which is attached the wire or cord which transmits the pull. A small safety catch completes this improvised friction tube.

Another deed, worthy of note, must be mentioned, one which was brought to a successful termination by Lieut. D. Juan Beigbeder, of the 4th Regiment.

There is a hill in front of and commanding the Second Blockhouse, which is defiladed from Sidi Musa and Sidi Amet-el-Hach, and where the Riff marksmen had established their posts, causing us frequent and considerable losses.

In order to check the impunity with which this hill was used by the Moors, Lieut. Beigbeder determined to place three mines in the spots occupied by them. He accordingly started at dawn on the 12th September with 20 men carrying tools and explosives. They mounted a slope 1,300 yards long in the open, and commenced their work, which was particularly dangerous as the mines were provided with detonating apparatus which acted on being inverted.

The Moors, observing the party, came up in great numbers with the intention of cutting it off, but were prevented from doing so by the fire of the Melilla Fortress Company, and of a section of the Alfonso XII. Regiment.

Lieut. Beigbeder's party was reinforced by 60 men of the Mérida Regiment under a second lieutenant, and carried on its work under heavy fire from the enemy posted on the ridge north of the ravine of Sidi Musa.

As soon as the work was completed the party retired, supported by the fire of the artillery of Sidi Musa, losing only one man wounded. The Riff marksmen then re-occupied their accustomed posts and exploded the mines which caused numerous casualties among them. Beigbeder's sappers, with Sergt. Mateos who distinguished himself in this operation, received many congratulations.

TELEGRAPHY AND RADIO-TELEGRAPHY.

The duties carried out by the telegraph troops from the beginning of the campaign have been extensive and difficult. At the very commencement of the operations they had to establish signalling and telephonic communications between the outlying forts, the fortress of Melilla and the outer positions occupied by the army on the 9th July. Afterwards, as brigades and divisions arrived at Melilla, their headquarters had to be connected with those of the Commander-in-Chief. Later on telegraph stations were established at la Restinga, Zoco el Arbaá, Nador, Zeluán, Zoco de Beni-Sicar, the Tres Forcas Peninsula, and accompanied the troops right up to the skirmishing line in various engagements. I have here an incomplete sketch of the work of the different telegraph companies.

The Telegraph Company of the 2nd Regiment started on the 23rd July for Melilla and arrived there on the 25th, camping with the remainder of the corps troops on the Melilla Gardens.

On the following day it established both a telegraph and telephone service between the extremities of the camp of the 1st Brigade, and joined the headquarters of this brigade with Fort Camellos. Three signalling stations were also established, namely, two at the headquarters of the 1st Brigade and one at the Posada del Cabo Moreno, all of which worked perfectly. On the 29th the telegraph line from one end to the other of the 1st Brigade was taken up; on the 30th a permanent telegraph line was established, with offices at the Hipódromo and the Posada del Cabo Moreno. All the necessary material was supplied from the Engineer stores of the fortress. Later on (on the 21st August) another station was established at the blockhouse between the Velarde and Second Blockhouses. On the same day two light optical stations and two loud-speaking telephone stations (the material being supplied by the Commanding Engineer, Melilla) were established between the encampment of the company and Fort Camellos.

Signalling stations had also been established on the 1st August at the blockhouse which was being built between the First and Second Blockhouses, and on the 5th, three more stations were established, one being close to the Bull Ring.

During its ascents the captive balloon was put in telephonic communication with convenient points.

Parties of telegraphists were formed for the purpose of repairing damage caused by the passing of trains and convoys, the breaking of posts, etc.

The fire of the artillery occasionally caused damage to the permanent telephone line between the Hipódromo and the Casa del Cabo Moreno, and it became necessary to lay out a cable along the ground, after which the line worked well.

During the early part of August telegraphic communication was extended from Melilla to la Restinga, the line passing over the tongue of land which separates the Mar Chica from the sea. At first the cable was buried, but it became necessary to take it up and place it above ground level on account of the faults caused by the damp. It was accordingly placed on posts, of which a large number 23′ long had been thrown up by the sea from some wreck. This aerial line worked perfectly.

By the 8th September the telegraph companies had the following lines established :—

The 4th Regiment, an electric line between Melilla and the advanced positions.

The 2nd Regiment, heliograph stations in the blockhouses on the railway, at the Casa del Cabo Moreno, and at Fort Camellos where were the headquarters of the brigade.

The 3rd Regiment, a telegraph and telephone line between Melilla and la Restinga, and when this line had been established General Marina had another telephone put up in the tent of his adjutants, so that the Commander-in-Chief could communicate with Melilla both by signalling, telegraph, telephone and wireless, and also directly with the fleet, and with Madrid through the wireless stations at Melilla and Almería.

In the engagement on the 20th September at Taxdirt the telegraphists of the 3rd Regiment, besides participating in the work of the sappers, established signalling stations which communicated with the Atalayón, with General Alfau to the north, and with the Commander-in-Chief to the north-east.

In the operations of the 20th, 21st and 22nd, the four signalling stations of the company commanded by Capt. Alvarez established communication, immediately the position was occupied, with those on the visible horizon. During the marches, a signalling station accompanied headquarters and worked directly under the orders of the General.

On the 22nd September, when Sotomayor's Division occupied the Zoco de Beni Sicar, the telegraphists of the 5th Regiment, a very few moments after the arrival of the vanguard, established communication with the fortress and with the units of Tovar's Division which was on the right. At dusk on the same day they laid a telephone line to connect the two brigades and joined them by telegraph with the fortress. Later on, as a consequence of the attack of the 28th September, a second telephone wire was laid between Zoco-el-Had and Sotomayor's headquarters (Hayara-Muna) so as to secure communication under any contingency, and there were besides six heliograph and lamp stations which worked both by day and night.

The services rendered by the telegraphists of Capt. Alvarez's company during the action of the 30th September at Beni-bu-Ifrur are worthy of special mention.

Signalling was constantly employed in the skirmishing line and General Tovar was kept in constant communication with the Commander-in-Chief.

At the beginning of October the following lines were working:—

2nd and 3rd Regiments.—Communication between their respective brigades and other stations.

4th Regiment.—Melilla—Atalayón-Hach.

5th Regiment.—Melilla—Benisicar.

6th Regiment.—Stations at Upper and Lower Nador and Zoco el Arbaá.

Fortress Telegraphists.—Service between the forts, Ait-Aisa, Tres Forcas, Cabo del Agua.

Telegraph Lines of the Mountain Sections.—Telegraphists of the 2nd Regiment.—From Sidi Hamet el Hach to Zeluán.

3rd Regiment.—Melilla—la Restinga.
4th Regiment.—Melilla—Second Blockhouse—Sidi Hamet el Hach.
5th Regiment.—Cabrerizas—Zoco de Beni Sicar.
6th Regiment.—Restinga—Zoco el Arbaá.

RADIO-TELEGRAPHY.

On the 6th September, the radio-telegraphic section under Lieut. Arbex started for la Restinga, and on the 8th established communication with the fortress.

The wireless station at la Restinga also communicated with the fleet, and occasionally with the station at Almería.

After the occupation of Zeluán it moved to the Alcazaba where it rendered excellent service.

Lieut. Arbex had to contend with great difficulties in regard to the transport of the vehicles which carried the wireless apparatus, as pack mules instead of draught animals had been issued for this purpose, and some of them went sick. The Balloon Company, however, helped by the loan of their animals.

RAILWAYS.

Two companies have been formed to exploit the mineral riches of the Riff country close to Melilla; one of them named the "Companía de Minas del Rif" is endeavouring to develop the rich deposits of iron ore contained in the Beni-bu-Ifrur Mountains; the other the "Companía del Norte Africano," better known as the French Company, although its head offices are in Spain, proposes to exploit lead mines. Both commenced, as a preliminary measure, to survey, and lay lines of railway (0·60-m. gauge in the case of the North African Company and 1-m. gauge in the case of the Riff Mines Company) which starting from Melilla are to terminate at the places where the minerals are worked.

The trace of the two lines from the Hipódromo to Nador runs parallel the one to the other along the eastern slope of Mount Gurugú, in the narrow space comprised between it and the Mar Chica. Close to Nador the lines diverge, that of the Riff Mines Company going towards the south-east, and that of the North African Company towards the south.

The attack by the Moors on the 9th July on the railway workmen of the North African Company close to the Second Blockhouse gave cause for the rapid and energetic intervention of the garrison of Melilla and to the occupation of the positions close to the line, such as those at the Atalayón, Second Blockhouse, Sidi-Musa and Sidi-Amet-el-Hach. From this moment a certain military *rôle* was imposed on this line, if it were only that of supplying the positions along it.

This line parallel to the chain of Gurugú which was occupied by the enemy must of necessity be open to attack therefrom. It could not be worked under normal conditions, and for this reason railway troops had to be employed.

On the 30th July a Railway Company left Madrid for Melilla and disembarked there on the evening of the 1st August.

It was encamped on the Melilla Gardens, where tents were pitched, but as the company had at once to take over the working of the North African line the captain asked permission to move to the neighbourhood of the railway station, where the new camp was established on the 5th August.

On the 8th August 50 men of the Railway Battalion under a second lieutenant arrived at Melilla as a reinforcement to the company. This enabled it to be organized provisionally into three permanent-way and and one telegraph sections.

Later on, when the company took over the whole working of the line including the engines, the captain entrusted the three officers of the company with the care of the rolling stock, traffic, and permanent way respectively.

Besides this and before taking charge of the whole service, men were lent to the director of the Spanish Company for the purpose of erecting the engines which had just been received.

Material of the Line.—The railway line of the North African Company has a gauge of 0·60 m. (2′), rails 23′ long and weighing 15 kilos. per metre. The platelaying had been done with but little care.

The rolling stock comprised :—

Two locomotives with 4 coupled axles, weight 16 tons.
One locomotive with 2 coupled axles, weight 8 tons.
Two open carriages.
One brake van.
Two 8-ton trucks.
Nine 6-ton trucks.
Nine 3-ton trucks.

The locomotives were in very bad order. The lubricators of the cylinders did not work, nor did half the valves. The two injectors, which each engine carried, acted very irregularly.

There was much friction between the members of the civil *personnel*, and it was often necessary to substitute men from the Railway Company for them, until finally on the 19th August the service was handed over to it, and, with the concurrence of the Management, the civil engine drivers were placed under the orders of Capt. Goñi who had power to impose fines and even to dismiss them in case of need.

Works Executed.—Immediately on arrival at Melilla the company received orders to repair the line which the Moors had destroyed a few days previously. A train was loaded with tools and materials and proceeded to the place where the damage had been done. The rails had been torn up and bent for about ½ mile, and for a greater part of this distance it was necessary to lay a new line, which was completed within three days. The company also cleared some clumps of prickly pear close to the line which served as cover to the Moorish marksmen.

The works were protected by infantry, but this did not prevent their having to be carried out under the fire of the enemy. On several occasions a part of the men of the Railway Company had to extend in skirmishing order to protect their companions.

It may be said that the construction and repair work was of a permanent nature, as the original state of the line was so bad that constant reconstruction was required. The French line had to be carried across the branch to Mar Chica which the Riff Mines Company had commenced, an operation which gave rise to difficulties of various kinds.

At the beginning of August a plan was prepared for prolonging the line to Nador, making use of the work which had been begun by the company, and as it was probable that this prolongation would be carried out later on, steps were taken for doing so.

Organization of the Service.—Up to the 10th August the service could not be suitably organized. On that date the Commander-in-Chief issued an order naming the stations at which convoys would stop, and prohibiting any unauthorized persons from travelling on the trains.

The stations named were the Hipódromo, as point of departure; the First Blockhouse; the Blockhouse; and the Second Blockhouse as railhead, and the following time-table was approved:—

Down Trains.

Stations.	Ordinary. 1.	Optional. 3.	Ordinary. 5.	Ordinary. 7.	Optional. 9.	Ordinary. 11.
Hipódromo	7.00	8.45	10.30	14.30	16.15	18.00
Casa Cabo Moreno	,,	,,	10.39	,,	,,	,,
Blockhouse	,,	,,	10.44	,,	,,	,,
Velarde	,,	,,	10.54	,,	,,	,,
Second Blockhouse	7.30	9.15	11.00	15.00	16.45	18.30

Up Trains.

Stations.	Ordinary. 2.	Optional. 4.	Ordinary. 6.	Ordinary. 8.	Optional. 10.	Ordinary. 12.
Second Blockhouse	8.15	10.00	11.45	15.45	17.30	19.15
Velarde	,,	,,	11.51	,,	,,	,,
Blockhouse	,,	,,	12.01	,,	,,	,,
Casa Cabo Moreno	,,	,,	12.06	,,	,,	,,
Hipódromo	8.45	10.30	12.15	16.15	18.00	19.45

The following Table will give an idea of the amount of traffic :—

Table showing the Movement of Trains, Passengers and Goods Transported on the North African Line.

		August.	September.	Total.
Number of trains		46	55	101
Number of passengers	Military	6084	2393	8477
	Civil	40	31	71
Hogsheads	Water	177	515	692
	Wine	71	31	102
Barrels	Water	1098	1892	2990
	Wine	13	28	41
Sacks	Rice	58	280	338
	Bread	937	3907	4844
	Potatoes	235	151	386
	Barley	338	1208	1546
	Sand	1500	—	1500
Packages	Food	1018	1668	2686
	Equipment	273	518	791
	Miscellaneous	2059	3293	5352
Bales of straw		869	2388	3257
Boxes of bacon		40	79	119
Dry vegetables		10	215	225
Loads of wood		27	41	68
Boxes of ammunition		528	996	1524
Posts and boards		2687	345	3032
Rolls of wire		79	21	100
Rails		190	—	196
Sleepers		615	—	615

On the 17th October the railway troops moved their camp from the railway station to the Hipódromo, and up to the 22nd October, the last date to which information has been received, they were engaged in taking convoys as far as the Second Blockhouse, besides serving in the trenches on the right flank of the Hipódromo camp.

CAMP WORK, ROADMAKING, ETC.

The work carried out by the C.R.E., Melilla, aided occasionally by the sappers, in preparing camps and making roads has been enormous.

At the end of July and the beginning of August shelters were made to house 5,000 horses and mules, a field bakery of four ovens, and a hospital.

In August wooden huts covered with Vidal cloth were made at the Second Blockhouse in which to store 100,000 rations, and others to contain ammunition for the Q.F. guns. The timber which had been cut and prepared in the shops of the fortress was rapidly put together.

At la Restinga the existing pier was repaired and lengthened ;

ovens were built, and storage provided for food and water. Help was also given to the navy in transporting a steam launch to the Mar Chica. The blocked channel which had previously existed, was cleared in order to connect the Mar Chica with the Mediterranean.

We have not included in this incomplete relation the important fortification and barrack worksat la Restinga constructed under the orders of Capt. D. Carmelo Castañón, which are shown in *Plates* XVI. to XVIII., nor those constructed by Lieut. Redondo at Cabo de Agua, all prior to the events of the month of July, as they merit a more detailed description.

In Melilla itself ovens were constructed, also huts for the wounded, for workshops and for artillery material, watering places, wells, shelters and many other works.

Water supply has also been one of the most important duties of the Engineers, as the provision of this necessary of life has been one of the most serious problems of the campaign.

Scarcity and even absolute want of water were noticeable from the beginning of July at the positions of Sidi Hamet, Sidi Musa, the Second Blockhouse, and the Atalayón, and caused great privations to the garrisons.

At the Atalayón during the second fortnight of July Lieut. Beigbeder rendered a signal service by opening some wells. He avoided a conflict and gave occasion for the sappers of the 4th Regiment, whom he commanded, to demonstrate once again their discipline and their devotion to their officers.

Capt. Iñiguez and the *personnel* of the district effected the opening of wells in the positions occupied by the troops by making bore holes down to the water strata and then widening them by means of explosives until a suitable diameter was obtained.

One section of sappers of the 3rd Regiment was employed at the end of August in sinking new wells at la Restinga.

When Aguilera's Brigade reached the position of Zoco-el-Arbaá, the sappers of the 2nd Regiment under Capt. Ortega opened 20 shallow wells which served to supply the whole camp. A similar work was performed at Anglat Wells.

In order to cope with the difficult problems of water supply, distilling apparatus which was obtained by Colonel Gallego was installed, and its erection and working were entrusted to the sappers assisted by numerous engine drivers and firemen supplied by the Railway Battalion.

The construction and laying out of roads have also absorbed a part of the energies of the sappers. Those of the 2nd Regiment were put in charge of the roads leading to Fort Camellos, the highroads to Cabrerizas and Rostrogordo, and others within the outer boundaries of Melilla. At Nador Capt. Ortega made a road $1\frac{1}{2}$ miles long leading to the neighbouring hills. The sappers of the 5th Regiment levelled the road which leads from Melilla to the position of the Zoco de Beni-Sicar. Our troops have also constructed piers and landing stages, amongst others one 132 yards long in the Mar Chica not far from Nador by Capt. Ortega's company, and another at Anglat Wells, in making which the sappers had to work up to their waists in water for 12 hours a day for 4 days.

Many other camp and roadmaking works have been performed by the Engineers, which the limited space at my disposal prevents me from describing.

The need for huts of a semi-permanent character in which to house men and animals was foreseen. Types have been studied, but the large sums required for these works for thousands of men and animals have not been available. It was, besides, necessary to know definitely the positions which they were to occupy and the corresponding garrisons. Nevertheless plans have been prepared for huts that can be easily erected, and a first instalment of wood and roofing material (Vidal cloth and Ruberoid) had been acquired, so that these important works could be put in hand as soon as ordered. In order to shorten the period of construction as much as possible, it will be necessary to call upon various building centres, as well as upon the labour at the disposal of the Commanding Engineer, Melilla.

OTHER SERVICES.

In addition to taking charge of the distilling apparatus which was installed under the direction of Lieut. Gáudara at Alhucemas, Melilla, Restinga and the Chafarinas, the men of the Railway Battalion were also responsible for the motor service.

The motor car which was patriotically placed at the disposal of the Commander-in-Chief by Señor Duarte, who at the same time voluntarily acted as its driver, was the origin of the service for which the broken nature of the ground is but little suited.

At the end of March, on the recommendation of the then Governor-General of Melilla, the Ministry of Marine took up the question of the provision of launches for use on the Mar Chica. For what we may call technical reasons they were not provided; and during September the War Office bought for service at Melilla, through the intermediary of the Commanding Engineer at Vigo, a steam launch called the *Europa* of which the principal dimensions are :—Length between perpendiculars 46½′, width 11′, draught 6′. On its arrival at Melilla the sailors understood that it was their duty to look after it, and acting under superior orders proceeded to disembark it and transport it to the Mar Chica, making use for this purpose of the railway belonging to the harbour works and of its civil *personnel* and not availing themselves of the services of the Military Engineers.

The launch was placed on three trucks, and on arriving at the first curve, as it had no doubt been badly loaded, it overturned and suffered serious damage.

EQUIPMENT OF THE TROOPS.

The Engineers during the Melilla Campaign have been provided with a very abundant and complete supply of material with which to carry out their varied duties, and their equipment will serve as a pattern to any army.

The sappers were provided with 20 pack field parks which contain an abundant supply of excellent tools for entrenching, demolition, mining and other purposes.

The Telegraph Companies took into the field:—

1 field wireless station, in addition to the two permanent stations at Melilla and Almería which have given excellent results.
60 signalling stations.
15 telegraph stations with 100 miles of cable.
26 telephone stations.
10 acoustic stations.

The Balloon Company was provided with:—

2 balloons, 1 spherical, the other kite shaped.
8 gas wagons.
450 cylinders of hydrogen at a pressure of 250 atmospheres and containing 4,000 cubic metres of gas.
1 photographic and observing equipment.

As the cylinders were emptied, they were returned to Guadalajara to be filled. The service between that place and Málaga was carried out with great rapidity, and the cylinders were returned to Melilla the same day as they were received.

For field electric lighting the Balloon Company was supplied with:—

1 90-c.m. projector driven by a steam engine, and 1 45-c.m. projector, both of which belonged to the fortress of Melilla.
1 90-c.m. projector with a petrol motor, which belonged to the park at Guadalajara, and which was sent to Melilla in June.
2 90-c.m. projectors were sent later from Palma and Mahón, and 1 60-c.m. projector from Mahón, all being provided with steam engines.
12 40-c.m. oxygenite projectors.

The Engineer Park at Melilla was supplied with a large number of tools from Santoña.

For the telegraph and wireless services, and in order to complete the equipment of the companies, there were sent:—

16 loud speaking telephones; 330 spare batteries; 31 miles of electric cable; a number of telegraph instruments.

There were sent for the Melilla Engineer District, and for the sapper companies :—

100 steel plates 2 metres long, 1 metre wide and 12 m.m. thick; 183,900 sandbags; 175 miles of barbed wire; 3,200 square metres of Vidal canvas; considerable quantities of large posts and building timber; 2,100 kilos (about 2½ tons) picrinite; 5,700 electric detonators; 2,600 metres of ordinary waterproof match; 17½ miles of electric cable for mining purposes in addition to what is carried by the pack sections; 10 dynamo exploders.

There exist in the stores at Guadalajara sufficient tools of 14 divisional sapping and mining parks, and 19 pack sections of a sapper field park are being constructed in the workshops at that place to make good those sent to Melilla.

Since the beginning of the campaign there have been obtained in view of fresh requirements :—

2 kite balloons and 1 spherical balloon.
1 Consorcius hydrogen generator.
1 dirigible balloon, which is now completing its trials.
1 portable wooden shed for housing the dirigible.
62½ miles of electric cable for mountain sections.
500 electric batteries.
2 field wireless stations on the Telefunken system.
2 light mountain wireless stations.
12 40-c.m. Barbier projectors, 6 with mirrors and 6 with lenses, and 2 Bleriot lamps.
2 lighting trains on the Barbier system, with 90-c.m. mirrors, petrol motors and distant control.
1 lighting train on the Sautter Harlé system with a 90-c.m. mirror.

Approval has also been given for the purchase of 125 miles of mountain electric cable, electrical instruments, two permanent wireless stations, as well as for material with which to instruct motor mechanics.

In order to secure the rapid arrival in Melilla of stores despatched from the Peninsula, Capt. Fernández Victori was posted to the Malaga Engineer District in place of Capt. Martinez Maldonado who was entrusted with the duty of hastening the loading and sailing of the transports. Capt. Acha and finally Capt. Suarez were posted to the Melilla District to look after the unloading, storage and distribution of the stores.

ENGINEER TROOPS AS COMBATANTS.

Engineers are combatants, not merely because they are armed with the rifle and act as infantry, but also because they often carry out technical duties under the fire of the enemy.

This truth has once more been verified in the Melilla Campaign. The sappers and miners and telegraphists have done duty in the trenches and have defended posts. During the marches in presence of the enemy they have formed the vanguard: they have taken part in the battles, either accompanying the advanced troops or further in rear, or as escort to the artillery. They have constructed works of defence, laid out lines of railway under the fire of the enemy, and established and worked telegraph stations in the firing line. We will mention a few cases amongst many which occurred during this war.

In order to prevent the destruction of the North African Railway line between the Hipódromo and the Second Blockhouse, it was decided to construct a blockhouse. The work which was commenced on the 2nd August, could not be completed by nightfall, by which time the parapet was about 4′ 6″ high. It was garrisoned by Lieut. Velarde of the infantry with 60 men, and a smaller number of telegraphists belonging to the 2nd Regiment under Sergt. Urbano Montesinos who had been sent to establish a signalling station for the purpose of communicating with the positions close to the fortress.

The enemy in considerable strength began to attack the blockhouse at 11.30 p.m. They surrounded the work and opened a hot fire, killing Lieut. Velarde and wounding 14 men. Under these critical circumstances the defence was taken over by the infantry sergeant and Sergt. Montesinos, each of whom took command of one-half of the little garrison and defended his own section of the work, until the enemy retired at dawn on the 3rd.

During the whole of the fight the telegraphists maintained communication with Melilla by means of lamp signalling, and kept the fortress informed of all the incidents, and of the necessity for reinforcements and ammunition.

The Moors took the lamp as a target, and Sapper Benito was badly wounded whilst working it.

The *personnel* of the signalling station took part in the defence of the fort, and during it one of the telegraphists repaired the damage done to the lamp by the enemy's bullets, so that communication was re-established with Melilla within an hour and a-half of the damage being done. During the fight Sapper Ricardo Aguado was wounded in the forehead, in spite of which he continued to take part in the defence, and was sent to hospital on the morning of the 3rd.

The sappers and telegraphists of the Fortress Company and of the 4th Regiment were repeatedly under fire in the actions which took place during July at the position which was occupied on the 9th.

The sappers of the 2nd Regiment defended the Lavadero Redoubt on the 27th July (Capt. Cueto), assisted at the engagement of Leedhara with Aguilera's column, and at the operations of the 6th and 11th September (Capt. Ortega). They always marched with the vanguard during the advance of Orozeo's Division from Zoco-el-Arbaá to Nador.

The sappers and telegraphists of the 3rd Regiment were under fire on the 20th September; and on the 27th the light sapper section of the vanguard of Tovar's Division, with Major Navarro, penetrated into the Alcazaba of Zeluán and made a detailed reconnaissance before the entry of the rest of the troops.

The men of the 5th Regiment, under the command of Major Ugarte, fought in the Zoco de Beni-Sicar during the night attack made by the Moors early on the 28th, in which the Riffs advanced up to the wire entanglements of the redoubts on the right flank of the position and cut them with reaping hooks. In this engagement the sappers suffered three casualties.

During the offensive reconnaissance carried out on the 30th September against the Beni-bu-Ifrur Mountains, a section of sappers under Lieut. Aguilar was in the vanguard with two companies of the Cataluña Light Infantry. Capt. Arana with the remainder of the company, and Capt. Alvarez and Lieut. Rivadulla with two signalling stations, were in the centre.

When the object of the reconnaissance had been gained and the troops were retiring in perfect order, they were furiously attacked by the Riffs. Lieut. Aguilar with his section remained fighting with the rear guard until he was ordered to retire with the two companies of the Cataluña Battalion, and his small detachment lost three men. Capt. Arana with Lieut. Sánchez-Cid deployed the remainder of the company and assisted the Figueras Battalion in supporting the retirement. Later on the sappers acted as escort to a mountain and Schneider battery.

The telegraphists with two signalling stations were constantly in communication with the Commander-in-Chief. One station kept close to General Tovar, and the other was with the rear of the column but always under fire of the enemy.

The Balloon and Searchlight Company has on several occasions carried out its duties under fire.

We have omitted many names and actions, as we are not writing a detailed history of the campaign; but what we have said will suffice to indicate our object.

LATEST INFORMATION.

The heavy rainstorms of the last fortnight of October have sorely tried our troops. It may be said that the Engineers have suffered more than any other troops from the inclemency of the weather, as they had to repair the great destruction caused by the torrential rains to the camps and light works of fortification which they were defending, and also to make good the damage to the telegraph lines between Melilla and la Restinga, and between the Zoco de Beni-Sicar and Sidi-Hamet.

The sappers, unlike the garrisons of Nador, Zeluan, etc., have never been relieved. Their labour has been uninterrupted in removing the sodden earth and working exposed to the wind and rain, so that they have suffered severely from sickness, and in some companies only 50 per cent. have been effective. It is not wonderful, considering the unhealthiness of the work, that the proportion of cases of enteric amongst the sappers has been greater than that amongst any other arm.

On the 22nd and 23rd October Lieut.-Colonel Ortiz de Zárate, Capt. Ruiz Capilla and Lieut. Alzugaray constructed two light bridges, 52′ and 55′ long respectively, over the Frajana and Rio de Oro, in a very short time, in spite of the rain and of the considerable increase in size of these small streams. It was necessary to relieve the garrison of Zoco-el-Had and this was effected by the aid of these improvised bridges which enabled the infantry, mountain artillery, mules and transport of the brigade to cross the rivers.

The Railway Company, to the great satisfaction of all the Military Engineers, has ceased to do duty on the branch of the North African Company's Railway and on the Riff Mines Railway.

OBSERVATIONS.

Fieldworks.—The organization, plan, section and materials of these works have been accommodated to the nature of the ground and of the enemy. He is not provided with artillery, and it is therefore unnecessary to keep the works low.

The Moors are armed with Mauser and Remington rifles, and know well how to make use of the least inequalities of the ground. They are very brave and are fond of surprises and night attacks, and therefore it was necessary to obtain good command over the ground outside the works, clear the field of fire as far as possible, and provide a good obstacle.

The nature of the ground, which is frequently rocky, made it necessary to construct sangars, backed up with earth, and crowned with sandbags. Stone could be used as there was no danger of attack by gunfire, and besides it has the advantage of facilitating the work, at any rate in its first stages. This is a circumstance which it is well worth while to bear in mind, for positions occupied during the day require to be rapidly placed in a state of defence, so that the garrison may be protected from any kind of nocturnal attack.

In order to attain the last-named object a barbed wire entanglement is an indispensable adjunct, as it forms an obstacle which cannot be crossed by an enemy. Barbed wire has proved itself most effective in the Melilla Campaign, as in other wars of modern times, and has been the salvation of the garrisons of many entrenchments from surprise attacks made by the Riffs during the darkness of the night. The enemy has, however, several times reached the first line of pickets with the intention of cutting the wires with reaping hooks.

The great expenditure of barbed wire and sandbags has been well justified.

It should be noted that our Engineers have had great difficulty in defilading the interior of the works in many of the positions which were occupied, such as the Lavadero Redoubt, Sidi-Musa, Sidi-Hamet, etc., owing to their having been commanded at short range by high hills.

In ordinary soil ordinary trenches were constructed. Every opportunity was taken in fortifying positions of utilizing the stone walls of the Moorish enclosures, market places, and houses. This was done at Zoco-el-Arbaá and on the Tres Forcas Peninsula.

Perhaps it may be said that the sections laid down in the Manual have not been adhered to, but every technical observer will appreciate the fact that the works have been well suited to the ground, to the nature of the materials, to the time available, and to the habits of the enemy, in fine that there has been a real application of field fortification to the ground.

In the construction of blockhouses, the Engineers have followed as a general rule the system of erecting a framework and covering it on the outside with boarding, protected by iron plates 0·4″ to 0·55″ in thickness. The timber was prepared in the workshops and transported to a suitable position where the blockhouse was built relatively easily and rapidly. Perhaps owing to the necessity of rapid construction, the walls have not been formed of two thicknesses of corrugated iron or of boards with the space between them filled with stones or earth, as was the custom in the Cuban and South African Campaigns.

Railways.—The campaign has been specially difficult owing to the total want of supplies in the country in which operations took place; everything had to be carried, and it was therefore necessary to have a constant service of convoys of food, ammunition and all classes of supplies.

The problem of transport from Melilla to the positions occupied by our troops has been one of the most difficult of those with which we have had to contend in this war. The large quantity of ammunition required by the infantry and artillery, the food, the stores required for the Engineer works, and the transport of the sick and wounded would have justified the employment of a military narrow gauge line, which would have followed up the movements of the troops along the line of communications from Melilla to Sidi-Hamet, la Bocana, la Restinga, Zoco-el-Arbaá, Nador and Zeluán. We must repeat, however, that considerations of another sort have forced us to use and prolong the civil lines which were in existence before the war.

The conditions under which the Railway Battalion has done duty at Melilla have not been so favourable as could have been wished. If the lines had been taken over altogether by the State, so that the whole of their working could have been entrusted to our railway troops, the work would have been much facilitated, although often carried on under fire, as the line was completely commanded throughout its course from the eastern slopes of Mount Gurugú. For reasons which cannot here be discussed the intervention of the higher *personnel* of these lines, and especially of the French line, in the movement of convoys has led to friction which would have been most prejudicial to the service had it not been for the zeal, energy and tact displayed by Capt. Goñi and his officers.

When work had to be done on the French Company's line, at a time when there was danger of attack by the Moors, the railway troops carried out their duties without friction or discord, but at the same time without the willing help of the civil staff; and when there was a question of industrial enterprise the co-operation of our soldiers in it did not accord with military regulations.

From all points of view the work of the Railway Company was worthy of applause.

Organization.—It has been observed that the sapper companies of the Light Infantry Brigades possessed a lower strength than the exigencies of the service required. It would have been well to have raised each company to 200 men, as has been done in the case of those attached to divisions. Owing to the nature of the country, the field park of each company was organized in three pack sections instead of in one pack and two wheeled sections. Thirty-six pack mules were required for each park, and to supply enough men to look after these animals severely taxed the strength of a company only 120 strong.

The very great amount of work that has devolved on the sappers and miners has shown that at least two strong companies are required with each division.

It also follows from the experience of this campaign that it would be convenient to attach a certain number of sappers and telegraphists to the headquarters of the Commander-in-Chief so that he may utilize them whenever necessary. This idea is not a new one, for in foreign armies Corps Engineers are found, as well as those attached to divisions.

When the Engineers are all distributed amongst the divisions and brigades their officers do not like them to be taken away from the units to which they are attached so that they may devote themselves exclusively to providing for wants of these units. Thus when the General Commanding the Engineers has himself to execute some service he has not the necessary means.

Camp and other Duties.—The transport of materials from Melilla to the place where they were required was not altogether satisfactory. Owing to the transport difficulties, preference was given in the convoys to rations and ammunition, and construction materials had to give place. These difficulties were increased whenever there was transhipment.

In order to obviate these difficulties Capt. La Llave, by order of Colonel Aguilar, posted a quartermaster at la Bocana who kept an account of all material brought thither by rail to be shipped on vessels in the Mar Chica. A sergeant of the 2nd Regiment performed similar duties at Nador, and another sergeant of the 4th Regiment at the Second Blockhouse.

Telegraphy and Wireless.—The telegraph companies always established communication between the headquarters of brigades and divisions and the Commander-in-Chief, and also with the fortress, and this communication was constantly maintained.

It was observed how desirable it would be that the General Commanding the Engineers and the General Staff should have at their direct disposal telegraph troops not exclusively attached to brigades, as the exclusive jurisdiction of the officers commanding these units was prejudicial to the effective working of the service of communications.

On some occasions, on the line between Zeluán and Nador, on account of special circumstances which necessitated the employment of very slow visual signalling only, the extraordinary volume of messages led to much delay. This was due to the inconceivably bad use made of this means of communication, the telegrams being unnecessarily long and couched in terms more suited to the office.

In general, the use of the telegraph and of signalling was abused. Messages of over 200 words were frequent, and everyone who had the right to send them did so to the fullest extent. For example, all the senior administrative officers forwarded daily tables showing the increases and decreases of articles of supply, with numerous figures, which filled the greater part of the capacity of the lines. These communications were also always marked urgent. It became necessary to call attention to the need for care in the classification of messages as laid down in regulations.

The use which has been made of the telegraph, and especially of signalling, both on the march and in battle merits attention. Examples of this service are the action of the telegraphists of Sotomayor's and Tovar's Divisions during the engagements between the 20th and 23rd

September, and of the company of the 3rd Regiment in the sanguinary reconnaissance on the 30th September in the Beni-bu-Ifrur District, when communication was constantly maintained between Tovar's Division, and the headquarters of the Commander-in-Chief, situated on a hill 2 miles away, the position being changed several times during the retreat.

The field wireless station has rendered valuable service. When the furious and long-continued rainstorm rendered all signalling and telegraphic communication impossible, the wireless station at Zeluán worked perfectly and kept the Alcazaba in touch with Melilla. This service is destined to develop greatly, and light mountain stations will be employed.

Ballooning and Searchlighting.—This was the first occasion on which these two services have been carried out in the field in our army, and they met with brilliant success. Before the war, inexplicable though it may appear, there were some who doubted their value, and who thought that the balloons would only be an incumbrance, and that the projectors would merely serve to draw the fire of the enemy. Let them consider the results of the reconnaissances of the 17th October and 30th September, let them glance at the graphic information obtained by our aeronauts about country which was quite unknown, though close to Melilla, let them recall the deadly effect of the artillery fire thanks to the information given by these elevated observatories, and they will have abundant proof of the imperative need of ballooning.

As regards field electric lighting, it is sufficient to say that the projectors have been asked for in all the positions occupied by our troops.

In fine, experience has sanctioned the employment of these most interesting services.

WHAT REMAINS TO BE DONE.

It is possible that the military operations may soon terminate and that the period of activity may be brief. However long it may be, the Engineers will participate in the operations in the interesting manner indicated in the preceding pages. With peace will come the rest so well earned by the troops, but new labours will commence for the Engineers, so that we may reap the fruit of the efforts of our arms.

The Spanish flag waves to-day from Cape Tres Forcas to Cape del Agua, in a strip of territory which circumscribes the peninsula of that name, and over the Mar Chica and the country bordering on it. The first problem that presents itself is the choice of positions which must be maintained. This is both a political and a military problem and is worthy of a more detailed study than we can give to it.

Spain has seen herself forced to take the place of the Sultan of Marocco, and to make up for his want of authority over the Riff Kabyles, so as to make herself respected. This has led us after hard-fought battles to the positions which are occupied to-day by our army. We have to maintain them, because those causes still subsist which have led us to occupy them, so that we may keep our unruly neighbours at a distance from Melilla.

The new positions are in the Guelaya country and form a new frontier. What is the character of this frontier ?

Up to the present Riffians have not been permitted to dwell within the limits of Melilla. The polygon marked out by the new positions comprises a part of the Frajana, Mazuza, Mezquita, Barraca, Beni-Sicar, etc., Kabyles, so that the same policy cannot be enforced within it. Its inhabitants must live with the Spaniards, for the war has not been one of extermination. They must not, however, be permitted to bear arms. It is needless to say that if this condition could be extended further beyond the new limits, the mission imposed upon Spain would be much easier. We must, however, look facts in the face and must therefore solve the problem on the supposition that our neighbours will be armed and supplied with ammunition.

Hence the works which we construct in the occupied positions which we have retained cannot be mere landmarks to show the limits of our territory, such as those which are planted in peaceful regions as a sign of possession and to prevent disputes.

The chosen positions and their organization must have a military value for offence and defence. A defensive value so as to prevent, as far as is possible in view of the broken nature of the ground and the character of the inhabitants, all aggressions on and incursions into the country behind them. An offensive value which can be estimated from the two following points of view :—The passive-offensive, which consists in menacing by fire the approaches, valleys, cultivated lands, *duars*, *zocos*, watering places and all those spots of which the preservation and enjoyment are of interest to the Kabyle, and which can be destroyed from our positions : and the active-offensive, taking the positions as a base for a further advance if there should be need some day for continuing the military action. In a word, the positions must be such as to afford a field for an offensive battle, suitable for the troops, and such that they can come up under cover and debouch against the enemy in convenient places. It must be in fine a manœuvre and training ground in peace time, of which the garrison will know every detail and where it will prepare itself for war.

The limits of this territory must be such as will correspond with the strength of the garrison of Melilla and with the facilities of supply and relief. Its trace cannot easily be determined. The new territory does not contain any roads, large villages, trade or industries which would form vulnerable points. The Riffs require no baggage when fighting, and the ground which to us is broken and difficult, is to them easy of access.

As to the defensive organization, we must not try to erect a kind of Chinese wall, but it will be well to limit it as far as possible to the dangerous passes and to watch the line well without multiplying the fortified points, as it is better to lessen their numbers and to increase their importance and radius of action. These conditions are partly antagonistic, and hence the difficulty of the problem of fixing the positions, in the solution of which it is necessary to consider the water supply, the facility of making communications, and many other important details.

The Zoco of Beni-Sicar and Hidun or the neighbouring place on the left bank of the Rio de Oro from whence there is a view of the Mediterranean both on the east and west of the Tres Forcas Peninsula, of Melilla and of Mar Chica, are positions which command the slopes of Mount Gurugú, the upper course of the Rio de Oro, and the valley of Frajana, and close the isthmus. With these positions and the one on the cape where the lighthouse has been established and with perhaps an intermediate one, it is possible to secure this part of the Beni-Sicar country.

The control over the southern shores of the Mar Chica, and the entrance to the plains of Zeluán and the Quebdana country can be secured by the occupation of la Restinga, and a position close to Zoco el Arbaá and Nador, and special attention must be given to a position which will maintain communication with Tauima and Zeluán. Even greater study is required of the steep Gurugú Mountains, a network of high peaks and of tortuous and hidden ravines, which have formed a constant menace to our land lines of communication with Nador and la Restinga, and which must be secured at all cost.

As regards the defence of the individual positions, it will be prudent to be prepared for a future attack by guns, even if only mountain guns. The works will certainly have to be provided with ample storehouses and magazines so as to diminish the need for frequently provisioning them, and to make them able to resist a blockade. They must have shelters, telegraphic and wireless communications, projectors, etc.

Numerous roads are also necessary, both giving well-covered and defiladed access to the positions from Melilla, and connecting the neighbouring works, and also roads for an advance. All these are required without prejudice to the utilization of the facilities of communication which are offered by the Mediterranean and the Mar Chica. The last especially will have to play a very important part.

There is urgent need of providing provisional accommodation for the garrisons of the occupied positions and of Melilla, and of transforming the field entrenchments into semi-permanent works, so as to be able to reduce the strength of the garrisons, without, however, interfering with their utilization in the definite permanent defence.

From the above one can judge of the magnitude of the task which awaits the Engineers.

CONCLUSION.

I will not end this little work without saying once more that there is no question of writing a complete history of the services of the Military Engineers in the Campaign of Melilla, but merely a light and incomplete sketch which has no other object than to give to the readers of the *Memorial* some information which will satisfy the natural curiosity awakened by the military events of which this African fortress has been the theatre between July and October.

I have certainly omitted to mention many deeds, names and services, not purposely, but only owing to lack of data and time. I leave to others better informed than myself the task of correcting my inaccuracies, and of remedying my deficiencies, and I send to our comrades Aguilar, Ortiz de Zárate, Ugarte, Navarro, La Llave, Ortega, Gordejuela, Herrera, Padilla and all those who have honoured me with letters and information, the expression of my thanks, and I offer to all, officers and men, my modest applause.

STATE OF THE ENGINEERS AND WORKS IN EXECUTION ON THE 10TH OCTOBER, 1909.

HEADQUARTERS STAFF.

Chief Engineer	Colonel Aguilar.	Melilla.
Attached F.O.	Lieut.-Colonel Ortis de Zárate.	
Secretary	Capt. La Llave.	

TROOPS.

Melilla District and attached Sapper Company.	Major Cabrera, Comg. Engineer.	Major Padilla—Melilla. Capt. Castañón (Carmelo)—Tres Forcas. Capt. Iñiguez—Tauima. Capt. Redondo—Chafarinas. Capt. Castañón (Droctoveo) (wounded): Lieut. Gándara—Alhucemas. Lieut. Alzugaray—Melilla. Lieut. Carcaño—Ait Aisa. Capt. Acha—in charge of park—Benisicar.
Balloon and Lighting Company.	Capt. Gordejuela. Capt. Herrera.	Lieut. Fernández Mulero—Zeluán. Lieut. Pou, Lieut. Combelles, Projectors { Camellos. Nador. Lieut. Barron—Melilla.
Railway Company.	Capt. Goñi.	Lieut. Balseyro—Motor Section. Lieut. Adrados, 2nd Lieut. E. R. Herrero, Convoys.
Wireless Station.	Lieut. Arbex.	2nd Lieut. E. R. Francia—Zeluán.
3rd Mixed Brigade (Imaz).	Major Catalá (Second Blockhouse).	Sappers, Capt. González Juan—Hach.: Lieut. Pérez Beato—Hach. Lieut. Bassa—Second Blockhouse. Lieut. Beigbeder—Second Blockhouse. Telegraphists, Capt. Francia—Melilla.: Lieut. Tarazona—Hach. Lieut. San Juan—Atalayón.

LIGHT INFANTRY DIVISION (TOVAR).

1st Mixed Brigade (Alfau).	Major Montero (wounded).	Sappers, Capt. Cueto—Zeluán.: Lieut. Moreno—Jeussart. Lieut. Gómez—On leave. Lieut. Alberca—Zeluán. Telegraphists, Capt. Seco—Zeluán.: Lieut. Aceytuno. Lieut. Sicilia. Zeluán.
2nd Mixed Brigade (Morales).	Major Navarro—Zeluán.	Sappers, Capt. Arana—Zeluán.: Lieut. Aguilar. Lieut. Lopez-Martínez. Lieut. Sánchez-Cid. Zeluán. Telegraphists, Capt. Alvarez—Zeluán.: Lieut. Revadulla—Zeluán. Lieut. Ostos—Melilla, Restinga.

1ST DIVISION (OROZEO).

Aguilera's Brigade. López Herrero's Brigade.	Major Andrade—Nador.	Sappers, Capt. Ortega—Nador.: Lieut. Molenello. Lieut. Albalat. Lieut. Montaud. Nador. Telegraphists, Capt. Nolla—Nador.: Lieut. Parellada. Lieut. Caamaña. Nador.

2ND DIVISION (SOTOMAYOR).

Brualla's Brigade. Ayala's Brigade.	Major Ugarte—Benisicar.	Sappers, Capt. Sauz—Benisicar.: Lieut. Aspiazu. Lieut. Sierra. Lieut. La Torre. Benisica (Zoco el Hach) Telegraphists, Capt. Suárez—Benisicar.: Lieut. Petrirana. Lieut. Ortiz. Benisica (Zoco el Hach).

3RD DIVISION.

Carbó's Brigade	Sappers, Capt. Pedrat—Melilla.: Lieut. Moriones. Lieut. Rodero. Lieut. Pedrosa. Melilla, Huerto Cañes.

AIDES-DE-CAMP.

Capt. Gallego.[1] 'Orderly Officer to the Commander-in-Chief.
Capt. Giménez (Fernando). Aide-de-Camp to General Sotomayor.

PART II.

After having written the article on this subject published in the *Memorial de Ingenieros* for October, 1909, fresh details were received, which, it is thought, will be of interest to our readers. Some of these details refer to works of defence and communications which have been constructed by the Engineers, and others are the result of reconnaissances and surveys which will give some idea of the topography of the country occupied by the Spanish troops.

The technical sections of the General Staff and Engineers are carrying out some notable topographical work on the positions.

FIELDWORKS AND CAMPS.

Zoco el Had.—This position has already been described in the previous article (*Plate* VI.). The defensive works which have since been executed in a semi-permanent manner are :—

(*a*). A redoubt for two companies and a battery.
(*b*). A redoubt for one company close to the position of the old Zoco.
(*c*). A redoubt for two sections and a 2-storied blockhouse.
(*d*). A redoubt for a section at the watering place.
(*e*). Two redoubts, one for a section at Mari-guari, and one for two sections at Hayara Muna.

The most important of these works is the redoubt for two companies and one battery (*Plate* XXVII.). Its plan consists of a straight front, with an emplacement for guns on each side, a gorge broken inwards, and connecting flanks.

The profile of the work is of a semi-permanent type. It consists of a dry stone wall, crowned at a height of 4′ 3″ by sandbags. A timber casing filled with broken stone forms a horizontal loophole all round the work. A ridge pole is placed at a height of 9′ and the rafters, which carry the roof of the shed in which the troops are quartered, rest upon it.

The resisting skeleton is formed by a timber frame which supports the casing above the loophole.

The gun platforms are raised so as to defilade the interior of the work. A wire entanglement forms an effective obstacle to escalade.

Two large huts have been built in the gorge, and another in the centre of the redoubt for the officers, as well as storerooms, cookhouses, etc.

Works at Nador (*Plate* XXVIII.).—The plate shows the trace of the works executed on the hills of Nador and Mount Arbós. The higher portions of the works are connected with the lower; both are provided with plenty of gun emplacements, especially Mount Arbós which, though lower than the hills to its right, commands a wide extent of ground.

At the foot of the hills, on the plain adjoining the Mar Chica, a field redoubt has been constructed (*Plate* XXIX.). Its irregular trace is due to the fact that it was first intended to be held by one battalion, but afterwards the garrison was greatly increased, and it became necessary to provide a larger interior space. It contains sheds for a considerable park of artillery, and for other purposes.

Major Andrade's sappers have built many well-designed works at Nador, including three large sheds 70′ × 20′ used as provision stores; a 2-storied blockhouse in the redoubt; pavements, conduits, etc.; guard-houses; a pavilion for the General; piers in the Mar Chica, etc.

Two other plates (not reproduced) complete the information regarding the country, and have been drawn by Lieut. Parellada. One is a sketch from the Nador orchards and a complete bird's-eye view of the country, the other shows the Nador position with the corresponding bird's-eye view.

Hidun-Iztmar adz Ifrain.—In the first article the Hidun position was described. It was occupied by our troops from the 20th to the 22nd September, then abandoned, and finally reoccupied. It flanks the Zoco el Had position, and helps to hold the left bank of the Rio de Oro and to close the entrance to the Tres Forcas Peninsula.

Redoubts have been built there for two companies, and a battery of 9-c.m. guns.

There is a commanding height called Hesyun about 1,100 yards from Hidun.

To the west of Hidun and about 1¼ miles from it, there is a plateau which slopes gradually to the sea, and ends on the coast line towards Cala Cazaza in an almost vertical precipice. A work for 100 men and a battery of 9-c.m. guns has been constructed on this plateau about a mile from the sea and about 650′ above it, so as to assist the works at Hidun and Zoco el Had in closing the entrance to the Tres Forcas Peninsula, and to watch the sea coast so as to prevent the smuggling of arms.

Sebt.—The position of Sebt, occupied on the 26th November, is an important one, as it connects Atlaten with Nador. It affords a view over the mountains of Afra, Jemis and Uixan, Segangan, and a great part of the railway of the Spanish Riff Mines Company. Guns in this position have a very wide field of fire, as they command the valleys of Atlaten and Beni-bu-Ifrur, and support the guns at Mount Arbós, Tauima, Ben Tajar and Atlaten. They also flank the far western side of the plateau on which Atlaten is situated, and command the road to Nador.

The work which has been constructed on this position (*Plates* XXX. and XXXI.) is garrisoned by two companies of infantry and a battery. Its plan provides gun emplacements which permit of the whole field of fire being utilized. Two advanced entrenchments for infantry, which are shown in the sketch, complete the defensive works.

Quartering of the Troops.—The increase in the garrison of Melilla necessitated the provision of temporary barracks, and wooden huts were used for the purpose.

The Commanding Engineer prepared plans for various kinds ot huts for men and animals, and commenced to make them, but found many difficulties in doing so owing to the scarcity of labour and of means of transport.

In order to facilitate the work, portable huts were sent from the peninsula 165′ long by 33′ wide, roofed either with Vidal canvas or ruberoid.

ROADS.

Melilla to Zoco-el-Had (see *Plate* XXXII.).—Immediately Zoco-el-Had was occupied steps were taken to construct a road connecting it with Melilla. The road is now finished, including the levelling, the roadway and the drainage, and some wooden bridges, which should be replaced by more permanent ones.

This road, the latter part of which is shown in *Plate* VI. of the article published in the October number of the *Memorial*, starts from Melilla, follows the right bank of the Rio de Oro, crosses it a little above its junction with the Frajana, and ascends the slopes on the left bank of the latter stream onto the plateau on which is situated Araya-Muna, the former position of the headquarters of Sotomayor's Division, and thence proceeds almost in a straight line to the redoubts of the Zoco.

Melilla to Hidun.—The road starts from Melilla; for the first mile it goes due west along the left bank of the Rio de Oro, leaving to the north the forts of Reina Regente, Cabrerizas Bajas and Cabrerizas Altas, and rising gradually all the way at an average gradient of 1 over 20.

The direction is then suddenly changed at right angles to the Rio de Oro and the road proceeds towards the north for about 1½ miles. In the first half-mile it ascends at a slope of 1 in 10. For the remaining distance the section is up and down, the average gradient being 1 in 50.

The road again changes its direction and runs towards the west for 1¼ miles, it then turns towards the south for another quarter of a mile. For the first quarter of a mile the slope is about 1 in 10 so as to ascend a small hill, and the remainder is undulating, until Hidun is reached.

Altogether the road is between $3\frac{1}{2}$ and 4 miles long and ascends to a height of about 720′ above the sea.

After reaching the hill of Hidun the road extends for a further 1,450 yards, in order to reach the works which have been built there, and which consist, counting from east to west, of:—one redoubt for one company, one redoubt for two companies and a battery of St. Chamond guns, and another redoubt for one company 1,100 yards to the westward.

This road is to be prolonged to the west through Hesyun (810′ above sea level) to Iztnar-at-Ifrain (645′ above sea level), $1\frac{1}{2}$ miles from Hidun.

Melilla to Teguel-Manin and Nador.—Before the war, during the first half of 1909, a public road was planned to start from near the slaughterhouse on the seashore about 300 yards from the left bank of the Rio de Oro, and to cross that stream by a bridge 23 yards wide. It was then to traverse the Triana quarter, and run parallel to the Spanish mining railway, and after crossing the Mezquita stream and leaving the Hipódromo on the left, to run between the two lines of railway as far as the Posada del Cabo Moreno. This is a first-class road 2,600 yards long and almost level, the greatest slope being 1 in 50 where it crosses the Rio de Oro.

Two branches start from the high road, the first leads from the Posada del Cabo Moreno to the position of Teguel-Manin and ascends the Mezquita slopes, the second runs to the position of Ait-Aisa.

The main road to Nador, after leaving the Posada del Cabo Moreno, follows the foot of the north-eastern and eastern spurs of Mount Gurugú, generally in a southerly direction, and passes the mouths of the Infierno, Lobo, Alfer and Sidi-Musa Ravines. It ascends for most of the way, though there are occasional descents, as it has to reach the top of the Atalayón Col, 85′ above sea level, between the Atalayón itself and the plateau of Sidi-Hamet-el-Hach, before gaining Nador. Although the road approaches more closely to the spurs of Mount Gurugú than the railway lines do, the slopes are gentle, not exceeding 4 or 5 per cent.

From the Atalayón Col the ground descends to Nador (33′ above sea level) 7 miles from Melilla.

From Nador to Zeluán, viâ Tauima.—The road crosses a wide plain, which offers no difficulties. It consists of two almost straight portions, Nador-Tauima and Tauima-Zeluán, making an obtuse angle at Tauima.

The construction of this road was commenced from Zeluán and is almost finished.

Nador to Atlaten.—The general direction is from east to west.

After passing Nador the road follows the plain of the valley of the Rio Uicsan, with very gentle gradients. It passes close to Segangan and the positions of Sebt and Ben-Tajar. The last part of the road to Atlaten (1,188′ above the sea) is very winding, with steep gradients, which, however, do not exceed those suitable for a mountainous country.

Existing State of the Roads.—The haste with which these roads have been built, so as to meet the requirements of the situation, did not always allow of the usual practice being followed in their construction. In some places the road bed was formed of large stones, as a first layer, with smaller stones as a filling, and a final layer of sand and gravel. The deficiencies can be made good.

The Commanding Engineer, Melilla, obtained an Aveling & Porter 12-ton steam roller for road work.

The existing state of the roads already mentioned permits the passage of fast and heavy motor cars.

High Roads belonging to the Public Works Department.—The Public Works Department has to deal with the making and extension of those roads, which are considered to be public thoroughfares leading to the port of Melilla.

The mixed civil and military committee appointed to consider them consists of the road engineers, Messrs. Becera, Fernández de la Somera and Díaz, Majors Andrade and Navarro and Capt. La Llave. Its recommendations are as follows:—

High Road from Melilla to the Col of Atlaten viâ Nador.—This road is to pass through the following points:—The junction of the Riff Mines Railway near the Second Blockhouse; the Atalayón Col; the Nador Col; the left of the Sebt position; the left side of Atlaten Hill, and the col of that name.

High Road from Nador to Zeluán.—This road will start from the last named at the level crossing at Nador, and will pass to the north of Tauima, and thence straight to Zeluán.

In view of the future military and traffic requirements, the width of both roads will be 26′, which is the ordinary width of a first-class road, the gradients are not to exceed 1 in 20, and the minimum radius of the curves will be 165′.

Melilla to the Zoco el Had.—This road will start from the Buen Acuerdo road near the level crossing over the railway to the quarries, will follow the left bank of the Rio de Oro, and cross it above its junction with the Frajana under the fire of Forts Reina Regente and Cabrerizas Bajas, and from thence will follow the military road to the Zoco-el-Had by the spur which divides the Rio de Oro from the Frajana, and will end at the Zoco-el-Had itself.

The maximum grade will be 6 per cent., the minimum curves 132′, and the width of the roadway in the clear 19′ 6″—a third-class road.

Melilla to Tres Forcas.—Length 19 miles. On account of the nature of the ground and the scanty population, a country road 12′ wide on the road bed, and 16′ 6″ over all, with maximum gradients of 1 in 12½ and minimum curves of 50′, is sufficient.

This road will start from the junction of the existing military road to Fort Rostro Gordo with the bridle path leading to Cape Tres Forcas. It will generally follow the top of the hills to the Col of Ayeman and thence along the existing road to Cape Tres Forcas, keeping along the eastern side of the peninsula until it reaches the low col at its end, from which a branch will run to the lighthouse.

Other Military Roads.—Various other purely military roads will have to be constructed, so as to connect the positions which have been occupied, and to satisfy the needs of the defence.

The first to be mentioned are those which must pass by the Jardú position, a high table-land transverse to Mount Gurugú, the military importance of which has been pointed out, and which must be strongly held by important works.

Jardú can be connected with :—

Teguel-Manin (this road was finished in the middle of February by a company of the 7th Regiment Engineers assisted by infantry working parties), passing by a narrow gap between the Peak of Basbel and a lower one to the south east, and following the western side of the Infierno Ravine.

Karmud, by the northern spur of the Peak of Basbel.

Ait-Aixa, following the edge of the Barranco del Lobo.

During the war, the Moors made use of two mountain roads in order to reach the plateau of Jardú. One of these paths runs along the eastern slopes of the ridge which terminates in the Peaks of Basbel, Aguja and Tagui-Griat. It then goes through the pass between the last-named height and the hill, 2,610′ above the sea, immediately to the south, so as to reach the western edge of the Taxuda plateau, and the ravines which start from Jardú and lead to Barraca by the gorge of that name.

Two roads can be constructed, one to communicate with Taxuda and to be prolonged to Atlaten, the other leading to Zeluán across Mount Gurugú.

The possibility should be considered of making a road from Taxuda which would follow the western slopes of Peaks 6 to 1.

If these roads were constructed, Jardú would become a centre of communications, and its value would be much increased.

The plans that may be made with regard to the Quert Valley, will determine the communications which will have to be made to it.

THEATRE OF OPERATIONS.

Ground.—Superiority of armament increases the probabilities of success in war, but though it powerfully contributes to success, it is not itself sufficient to gain battles and campaigns. Victory is made up of many elements, and a foremost place amongst them is taken by a knowledge of the geography and topography of the theatre of operations, of the nature and resources of the country, and of the character of its inhabitants and of their leaders. The plan of campaign should be based on these data, both as regards tactics and strategy.

It must be confessed that before the war we did not possess this knowledge of the country in which we were to fight, and whilst it was known approximately what line would have to be followed by the railway to exploit the iron mines of Uixan, and its longitudinal section had been determined, Mount Gurugú was completely unknown. This mountain, thrust like a wedge into our territory, allowed the enemy to menace and attack the line of operations which the events of the 9th July compelled the Commander-in-Chief to adopt. This circumstance was all the more unfavourable as the Mar Chica, which should have supplied the deficiencies and facilitated communication, could not be used owing to want of preparation.

When a mountainous district forms only a small part of the theatre of operations it may be more or less avoided, and the solution of the tactical and strategical problems may be sought in the low ground. When, however, the theatre of war consists altogether of a broken and abrupt country, occupied by a brave enemy who knows it thoroughly, can traverse it in all directions, and who defends his hearth with an enthusiasm inspired by a holy cause and by religious fanaticism, tactics cannot be based entirely on the rules applicable to open countries and to regular warfare. It is not prudent to venture into the valleys without securing the hills, and in this, more than in any other kind of war, endeavours should be made so to conduct the operations that the enemy's communications are threatened, and for this purpose a thorough knowledge of the ground is essential.

In the previous article we have given details of the theatre of operations, supplied by the officers of the balloon and sapper units. These were amplified with the results of the reconnaissances and sketches of Capts. Herrera and García de la Herrán, and Lieuts. Echagüe and Parellada, made during last December.

The structure of Mount Gurugú was made known for the first time thanks to the observations made from the captive balloon which ascended from the Hipódromo, la Bocana, Restinga and Nador (see *Plates* I. to V., VII. to XIX. of the previous article). In these plates it can be seen that the central mass is composed of a chain of peaks marked by the numbers 3 (Kol-la), 10 and 9, with another peak detached towards the south. They run approximately north and south, and give rise to the gorges of Alfer, Sidi Musa, Sidi Hamet, etc., which run down to the Mar Chica. There is another chain composed of Peaks 1 (Basbel), 2 (Aguja), and 6 (Tagui-Griat), which form the high ridge running from north east to south west, with another Peak 5 (*Plate* XXIV.) to the south of 6. The existence of ravines and high plateaus in the interior of these two chains of peaks could be inferred, but the spurs on the south-west and west sides were not well known.

The observations made from the balloon Reina Victoria, from a height 2,970′ above Hidun, permitted the whole country west of Gurugú to be searched (see *Plate* XXXII.). Later on, reconnaissances made in the interior of the mass have completed our knowledge. These reconnaissances and the panoramic views taken from Hidun, Sidi Mesaud, Sebt, etc., as well as sketches and plans, are all the work of Engineer officers, and give a just idea of the broken nature of the country.

The following is a list of the drawings referred to :—

Sketch obtained directly with the topographical material belonging to the Sapper Pack Park and from observations made from the kite balloon Reina Victoria (Capts. García de la Herrán and Herrera).

Sketch of the inner mass of Gurugú and the Jardú position (Capt. García de la Herrán).

Bird's-eye view from the Kol-la Peak (No. 3) (Capt. García de la Herrán).

Panorama of Gurugú from the Peak of Basbel (No. 1) drawn by Lieut. Parellada.

Bird's-eye view from Tagui-Griat (No. 6) by Capt. García de la Herrán.

Bird's-eye view (second and third quadrants) from a point 2,200 yards north east of Atlaten (1,155′ above the sea) drawn by Capt. García de la Herrán.

Bird's-eye view from Hidun.

Bird's-eye view from Sidi Mesaud by Lieut. Ortiz.

Zeluán.

Mar Chica. Sketch and bird's-eye view by Lieut. Parellada.

The two chains of Peaks 1, 2, 6 and 3, 10, 9 (*Plate* XXXII.) are joined so as to form a kind of H by a high plateau, running north east. Two small ravines start from it and unite to form the Barranca del Lobo between Peaks 1 (Basbel 2,510′) and 3 (Kol-la 2,376′). The eastern side of this ravine is formed by an abrupt spur from the Peak of Kol-la (3), on which, about a third of the way up from the base, Peak 4 (Taxit-el-Arbi 810′) rises in the form of a cone with a rounded spur running towards the east. The position of Ait-Aixa is situated on this spur, at a level of 528′, which, with the higher part of the spur from Kol-la, forms the Alfer Gorge.

Peak 10 (1,650′ level) forms with the southern spur of Kol-la the ravine of Sidi Musa. The position of Sidi Musa lies between it and the Alfer Gorge, at the foot of the spur from Kol-la. Further to the east is the Second Blockhouse.

A spur runs out from Peaks 10 and 9 (2,080′) and ends in an almost level plateau called Sidi-Hamed-el-Hach. To the south is the small hill named Sidi-Ali, and a ravine which runs down to the Mar Chica. To the east of Sidi-Hamet is the Atalayón, a conical hill 300′ high which extends into the Mar Chica, and along the northern side of which there is a considerable depth of water.

The high table-land known as Jardú stretches out from the south of Peak 3 (Kol-la) and joins the Ridge 1, 2 to the south of 1 (Basbel). The highest part, on the east, is 2,145′ above the sea, and the lowest part, on the west, 1,914′. The latter forms a small pass giving access from the Barranca del Lobo to the ravines on the south of the table-land, which unite to form the Barraca Gorge, running approximately north west and south east.

The topographical position of this table-land is very important. It commands the ravines to the north and south; it observes to the north Melilla and its territory, the mining railways at their commencement, and a part of the Tres Forcas Peninsula, and to the south Zeluán and the neighbouring hills, Sebt and other points. It will be understood what an unfavourable influence was exercised over the earlier operations by this plateau when it was held by the Moors. It dominated to the north and east all the ravines and avenues leading to the line of operations Melilla–Sidi-Hamet, and as a central position, permitted the enemy to make rapid radial attacks to the north and east against our right flank. It also formed a magnificent observatory from whence the movements of our troops could be watched from the time they left Melilla or their encampments. On the south it favoured the bringing up of reinforcements in the whole sector comprised between Nador and the upper reaches of the Rio de Oro.

A ridge runs out to the north east from Peak 1 (Basbel) and gives rise to two ravines, the Mezquita on the west, and the Infierno which lies between the Mezquita and the Lobo, and which starts between Basbel and a lower peak on the east. On the ridge between the Mezquita and Lobo Ravines, there is a hill (760′) called Teguel-Manin which commands the village and ravine of Mezquita, and the roads and railways from Melilla.

Another spur runs in a northerly direction from Basbel and forms the Mezquita Ravine as well as the ravine in which an affluent of the Rio de Frajana flows. The ground, which is very steep in the upper part, forms a plateau lower down, known as Karmud (1,188′), about $1\frac{1}{2}$ miles from Teguel-Manin and from the plateau (935′) of Zoco-el-Had de Beni-Sicar.

The ridge between Basbel, Peaks 2 (Aguja 2,670′) and 6 (Tagui-Griat, the highest point 2,805′ above the sea) gives rise to numerous ravines which run down to the Frajana.

A spur extends from Peak 6 (Tagui-Griat) towards the north west, and gradually widens out towards the north until it joins the plateau of Zoco-el-Had de Beni-Sicar, which forms the watershed between the Rio de Oro and the Frajana.

To the south of Peak Tagui-Griat and 1,100 yards away, another peak rises to a height of 2,610′. The pass between them is 2,274′ above the sea. A small ridge extends from the last-named peak in a south-easterly direction and terminates in Peak 5 (2,040′).

The series of hills 2, 6 and 5, and 10, 9 and the high transverse plateau of Jardú form the small and steep basin of the Rio de Barraca.

Spurs of Gurugú.—To the south of the 2,610′ peak, the high table-land of Taxuda (2,040′) forms a continuation of the southern spur which extends from Peak 6 (Tagui-Griat). Another wide plateau runs out from it to the south, and ends at Atlaten (1,188′). A still larger spur, extending first to the north west and then to the north, forms, with the first named, the upper basin of the Rio de Oro.

The plateaus of Taxuda and Atlaten form the watershed between the Rio de Oro and the streams which flow to the south east into the Mar Chica.

The steep spur which extends from Taxuda to the north west and north forms the watershed between the Rio de Oro and the river which debouches in the Cala Cazaza. The base of the Tres Forcas Peninsula is closed by the hills of Sidi Amaran, Iztmar-adz-Ifrain, Hesyun, and Hidun. The mountain of Tauret-Temarden rises from this spur to a height of 720′. The small conical hill of Kola, close to the sea at Cala Cazaza, is crowned by the ruins of a Roman fortress. The village of Tisa is on the left bank of the Rio de Oro, and Mount Tussalid (675′) on the right.

To complete the list of the outlying features of Gurugú we have :—

Sebt, a conical hill 360′ high, situated about half-way between Atlaten and Nador. From it can be seen the plain of Zeluán, the Afra Mountains, and the northern slopes of the Uixan chain, where lie the mineral deposits which the Spanish Riff Mines Company is trying to exploit (see *Plates* XXX.—XXXI. and XXXII.).

Ben Tajar, the last link of the southern spurs which extend from Taxuda, 891′ above the sea.

Hills of Nador and Mount Arbós, the extremity of the south-eastern spur of Gurugú. They form a horseshoe, with Nador (480′) and a lower hill (450′) on its eastern side. The western side is formed by Mount Arbós with two summits, the higher 408′ and the lower 342′ above sea level. A small hill close to the hermitage of Sidi Salem lies immediately to the north.

The view from Mount Arbós includes the plain of Zeluán, Atlaten and the ground bounded by the Beni-bu-Ifrur Range.

Important Rôle of Gurugú in the Battles of July and August.—The railway lines which run from Melilla to Nador and the mineral deposits in the Afra and Uixan Mountains, are laid out according to technical requirements. They have Nador as an obligatory point, and are compelled to wind along the sides of Mount Gurugú in the narrow space between the foot of the eastern spurs and the shores of the Mar Chica. They keep as close to the latter as possible, and as far from the hills, so as to avoid steep gradients, sharp curves and difficulties of construction and working. From the military point of view these lines could not be worse, whether their defence or their use as lines of operations be considered, so long as Gurugú is held by an enemy. They are commanded by musketry fire in such a way that it is difficult to defilade fieldworks from points outside them; they can be broken at many points, and the garrisons of the defending works surrounded and cut off from Melilla. There is a want of water and supplies for the garrisons, which have therefore to be provisioned by daily convoys constantly subjected, after leaving the limits of the fortress, to the commanding fire of the enemy.

The exact knowledge which we now possess of Gurugú enables us better to appreciate its importance. By its structure, it forms a great natural fortress, shaped like a redan, inserted like a wedge into the country to the south of Melilla, and with a gorge open to receive all the Riff Kabyles from the Tres Forcas Peninsula to the Ulad-Settat district.

The defenders of this great natural redan were covered from our fire, which, though curved, had very little effect, owing to the want of suitable targets and of means of observation. They occupied an admirable central position which permitted radial offensive action and the utilization of the numerous ravines, whose steep and open sides protected them from surprise and offered innumerable artificial and natural shelters, providing many excellent positions for sharpshooters.

The left flank of this redan was secured at its base by the intricate and rugged ground which forms the basin of the Rio de Oro, and was defended by the Beni-Sicar. Its right flank rested on Nador.

From this elevated observatory the enemy was able to obtain full information regarding the movements of our troops from the earliest moments, and thus gained the time required for making their defensive and offensive dispositions. During the night they descended from the mountain and lorded over the country.

It can thus be understood how difficult it was during July and August to support the posts along the line from the Hipódromo to Sidi-Hamet-el-Hach, and how sanguinary were the battles. These latter had, however, the salutary effect of accustoming our brave soldiers to war and of familiarizing them with the kind of fighting that was required.

It would have been very risky to have attempted to carry so formidable a redoubt by force, no matter whether recourse were had to the slow procedure of a siege or to enveloping movements designed to menace the lines of communications. This shows the importance and efficacy of the operations which were directed against Nador along the southern shores of the Mar Chica.

As it is not our intention to write a history of the campaign, we will conclude by pointing out the very important part which was played by Mount Gurugú whilst it was in the possession of the enemy, from which it is not difficult to deduce the *rôle* which it will have to play now that it is in our power.

DEFENSIVE-OFFENSIVE OCCUPATION OF THE THEATRE OF OPERATIONS.

This is not a suitable occasion on which to propose solutions of the problem of indicating the positions which should be fortified, armed and garrisoned so as to serve the double object of assuring the occupied territory and of preparing for fresh offensive operations.

This work has been carried out by very competent committees, who will assuredly resolve the problem in a satisfactory manner, in spite of its difficulty.

There has been much discussion as to whether the possession of the mountains ensures the mastery of the valleys, or whether on the contrary the mastery of the valleys ensures possession of the mountains. In problems such as these there are a great many factors which affect the solution. The extension which it may be desired to give to the occupied territory; the magnitude of the sacrifices which can be made; the topography of the country, its resources, degree of civilization, character of its inhabitants, etc., are important elements which cannot be ignored.

The present case is a singular one. A country in arms has to be occupied in a peaceful manner. Every inhabitant capable of bearing arms possesses a rifle. Respect for the rights of property hinders the clearance of the field of fire in the vicinity of the posts of the prickly pears, mud walls, etc., which favour ambuscades. Although the country is thickly populated, there are no great and wealthy centres of population which might serve as hostages, nor important cross roads or junctions which might form decisive tactical and strategical points. The broken nature of the ground makes both transport and supply difficult.

On the other hand the armed inhabitants know the smallest foot-paths, they are acquainted with the least movement of the troops, they can march individually and unite for action, whilst we cannot risk small detachments and have to seek security in concentrated columns. When the problem of the military occupation and defence of the positions is presented in this guise, it will be agreed that its solution will not be along ordinary lines.

It is understood that it is intended to maintain almost all the positions already occupied, viz. :—

Iztmar-adz-Ifraín, Hidun and Zoco-el-Had, at the base of the Tres Forcas Peninsula, and to connect them with the northern spurs of Mount Gurugú by making use of the positions of Karmud and Teguel-Manin, and, more to the east, those of Taxit-el-Arbi and Ait-Aisa, and to preserve the Lavadero Redoubt.

Along the eastern spurs of Mount Gurugú only Sidi-Hamet-el-Hach will be retained, as the magnificent position of Jardú will certainly be occupied strongly by a permanent defensive work of large size.

La Restinga, Nador with its hills and Mount Arbós; Tauima and Zeluán with the neighbouring position of Bu-guen-Zein; Atlaten with the two auxiliary positions of Sebt and Ben-Tajar; which are now occupied by our troops will be retained. The posts along the railway lines from the Hipódromo and the Casa del Cabo Moreno to Sidi-Hamet-el-Hach will be abandoned, except the Atalayón which will be preserved.

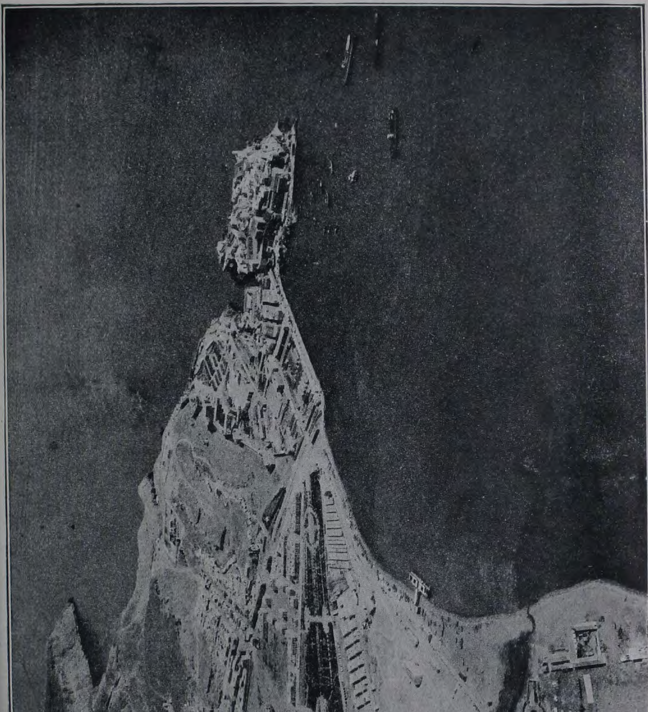
We are unaware whether Taxuda will be occupied or any other positions towards Tlet or Tidienitz in the direction of the Kert, or *viâ* Tussalid, Tissa and Temarden towards the hill of Amarán, for the purpose of joining hands with Hidun and Zoco-el-Had. This is not an opportune moment for discussing matters which are under consideration. When more complete data are available we will again occupy ourselves with this question.

PLATE I.

1 and **3,** peaks of Gurugú which form the Barranco del Lobo.

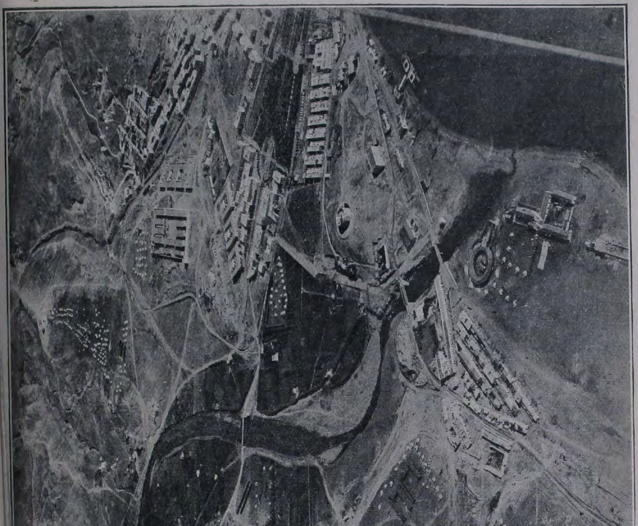
1, 3, 4 and Lavadero, theatre of the operations of the 23rd and 27th July.

PLATE IX.



Melilla and its exterior territory.

PLATE X.



Camps on the exterior territory of Melilla.

PLATE XI.

2nd Caseta.

PLATE XII.

Mar Chica and el Atalayón.

PLATE XIII.

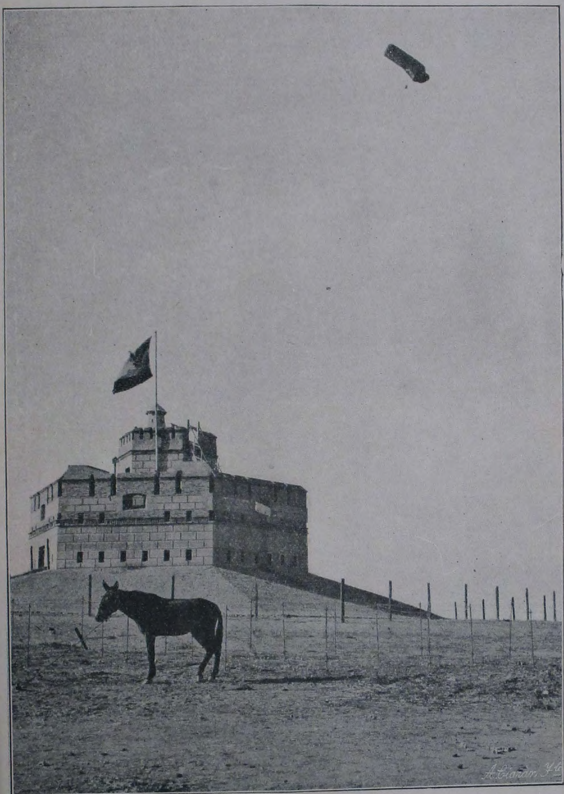
Inflation of the kite balloon at la Restinga.

PLATE XIV.

Ascent of the kite balloon at la Restinga.

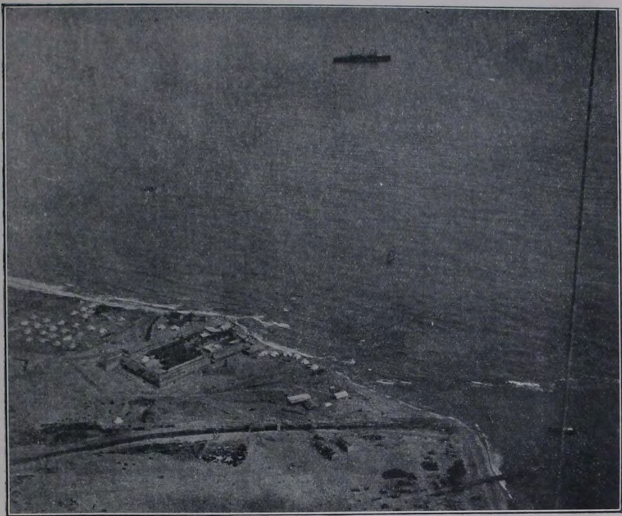
PLATE XV.

FORT OF LA RESTINGA.



The kite balloon in action.

PLATE XVI.

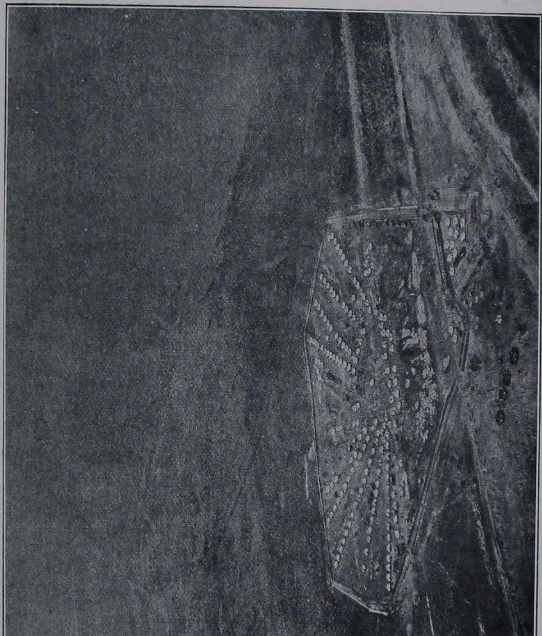


Restinga, from the Mediterranean.

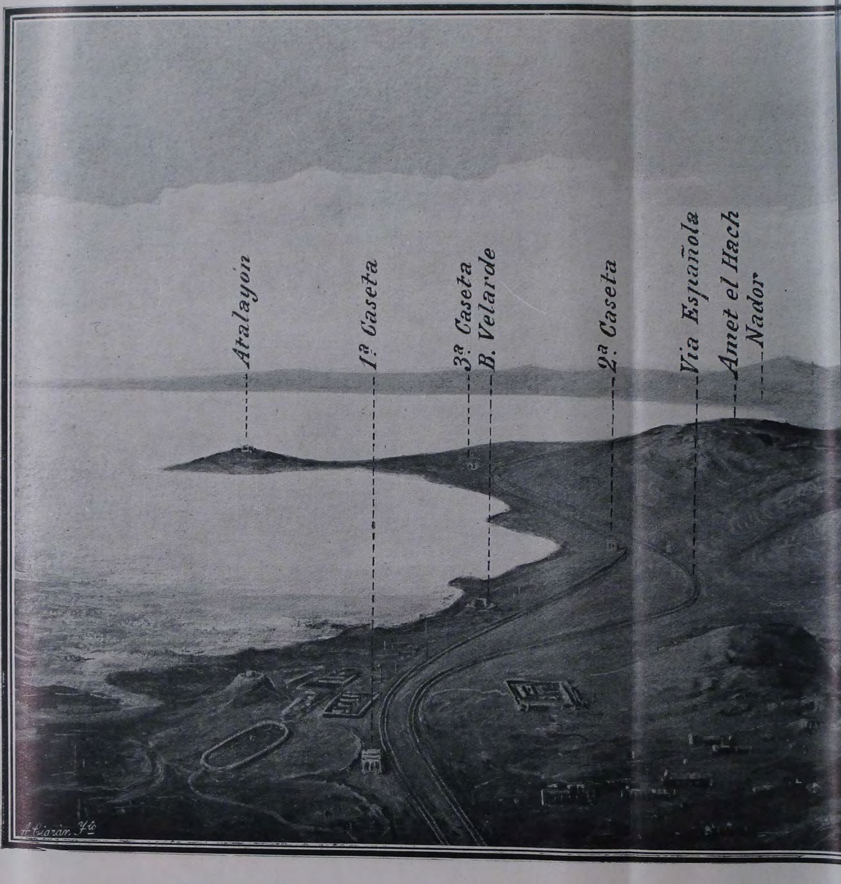
PLATE XVII.

Restinga.—Camp.

PLATE XVIII.



Camp of Zoco-El-Arbaa.



Barranco del Lobo and pos

PLATE XIX.

posit s occupied (from photographs by Gordejuela).

PLATE XXII.

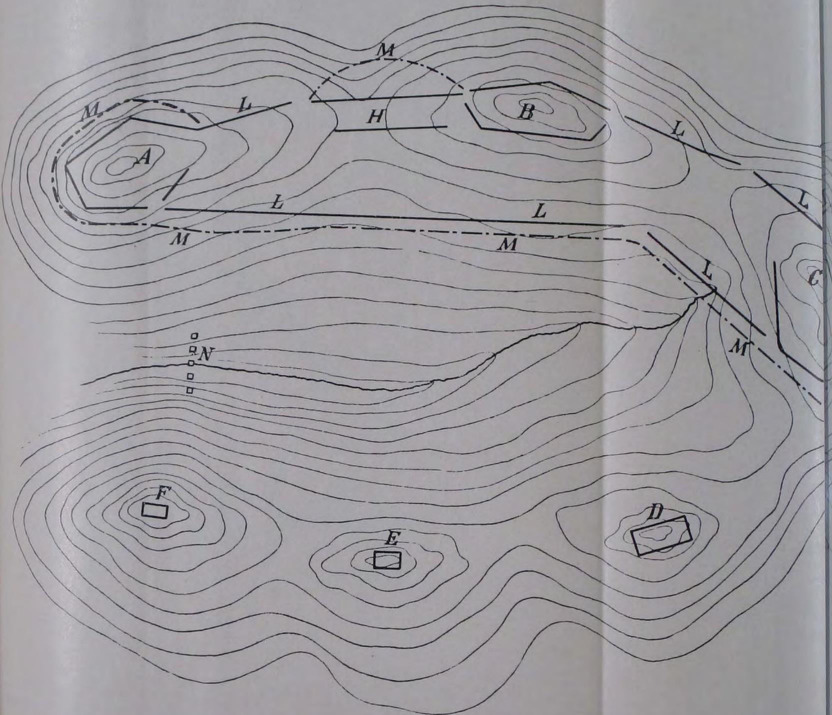
Rio de Oro and Sotomayor's Position (Had).

PLATE XXIII.

Taken from the balloon.

Cróquis de los bajos del embarcadero de la Restinga (*Sketch of the shoals at the landing place at la Restinga*).

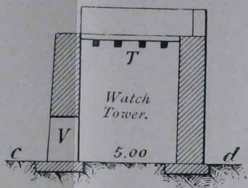
Fig. 1.



A Redoubt for one company.
B Ditto.
C Ditto.
D Ditto for one section.
E Ditto.
F Redoubt for one section.
H Battery.
L Parapets.
M Line of wire entanglement.
N Position of the fougasses.

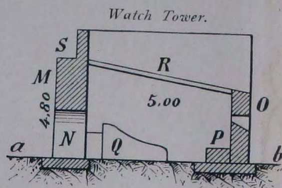
Fortification of Bu-guen-Zein to the N.W.

Fig. 2.



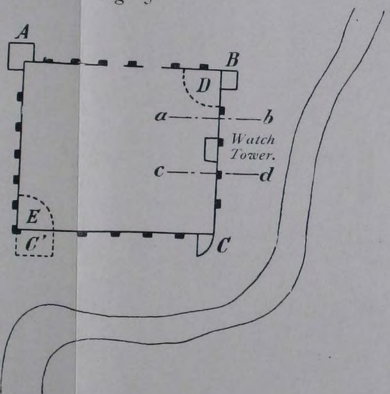
T Floor boards and baulks.
V Small door opened in the wall.

Fig. 4.



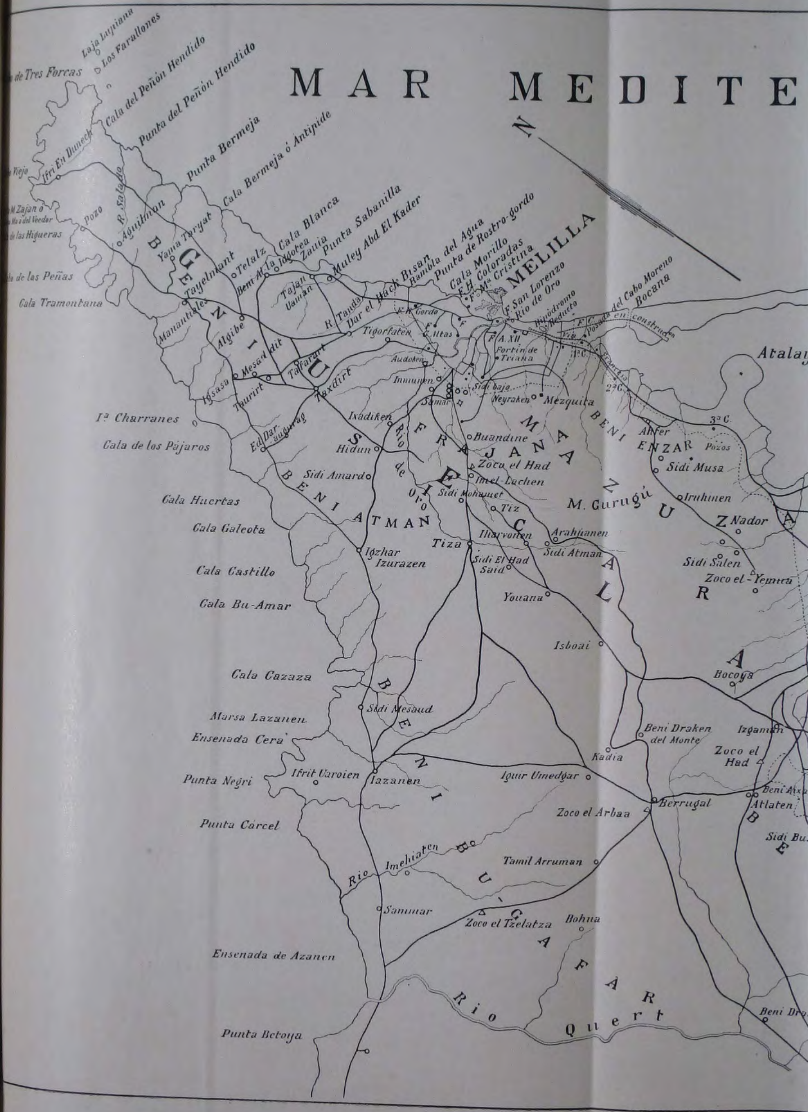
M Wall of the Alcazaba.
N Doorway made in the wall.
O Projected wall joining the watch towers on the outside.
P Banquette for fire through low loopholes.
Q Cuadra.
R Light roof.
S Projected parapet.

Fig. 3.



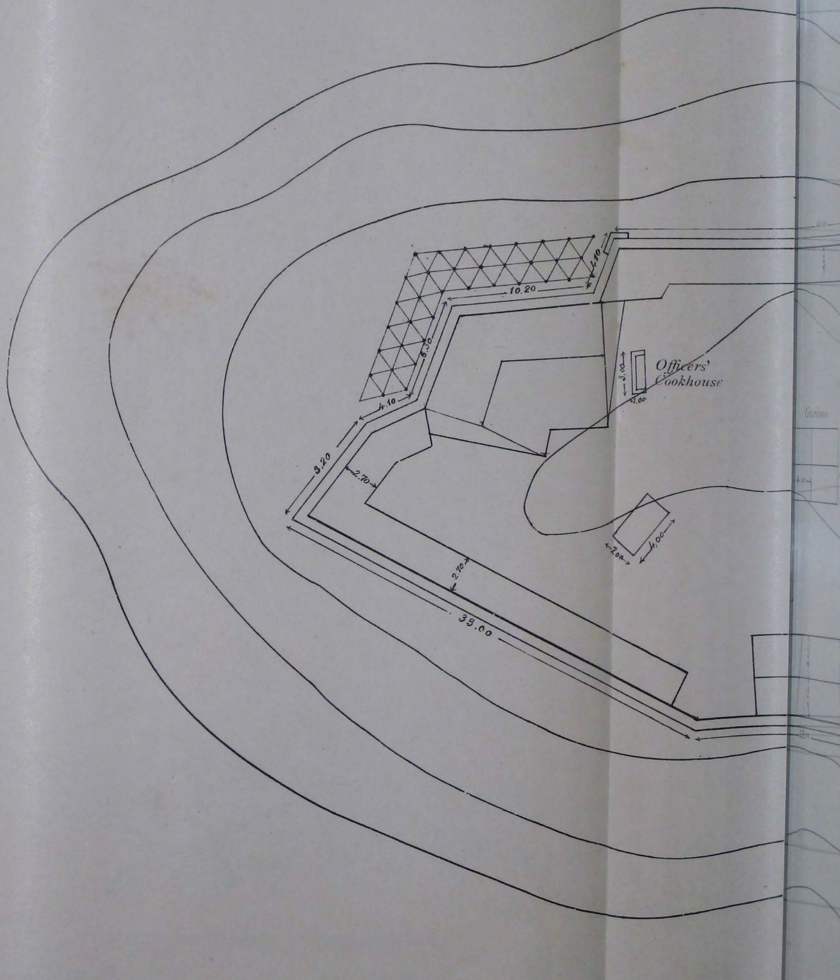
A Redoubt for two companies.
B Ditto for one ditto.
C Ditto for one ditto.
D Position for one battery.
E Ditto.

...he Alcazaba de Zeluán.


MAR MEDITE
N
MELILLA
Laja Lupiana
Los Farallones
de Tres Forcas
Cala del Peñón Hendido
Punta del Peñón Hendido
Punta Bermeja
Cala Bermeja ó Antipide
Cala Blanca
Punta Sabanilla
Muley Abd El Kader
Rambla del Agua
Punta de Rostro-gordo
Cala Morillo
Coloradas
Cristina
San Lorenzo
Rio de Oro
Hipódromo
Reducto
Posada del Cabo Moreno
Bocana
en construcción
Ifri En Duneck
Pozo
R. Salado
Aguilman
Yama Taryat
Tayelmant
Telalz
Zauia
Tajan
Uaman
R. Tanda
Dar el
Tigorfaten
Audoken
Inmunen
Samar
Sidi bajo
Neyraken
Mezquita
Cala Tramontana
de las Peñas
Manantiales
Algibe
Mesad dit
Igsasa
Taurirt
Taxdirt
Ixadiken
Hidun
Sidi Amardo
Rio de Oro
Buandine
Zoco el Had
Sidi Mohamet
Tiz
Iharvonen
Arahjianen
Sidi Atman
Tiza
Igzhar Izurazen
Sidi El Had Said
Youana
Isboai
Iª Charranes
Cala de los Pájaros
Cala Huertas
Cala Galeota
Cala Castillo
Cala Bu-Amar
Cala Cazaza
Marsa Lazanen
Ensenada Cera
Punta Negri
Punta Carcel
Ensenada de Azanen
Punta Betoya
BENI ATMAN
BENI SICAR
FRAJANA
MAZUZA
BENI ENZAR
M. Gurugú
Atalay
3ª C.
Pozos
Sidi Musa
Iruhinen
Nador
Sidi Salen
Zoco el-Yemma
R
A
Bocoya
Sidi Mesaud
Ifrit Uaroien
Iazanen
Iguir Umedgar
Zoco el Arbaa
Berrugal
Beni Draken del Monte
Kadia
Izgamun
Zoco el Had
Beni Aixa
Atlaten
Sidi Bu
Rio Imehiaten
Sammar
Tamil Arruman
Zoco el Tzelatza
Bohua
BU-GAFAR
Rio Quert
Beni Dr


DITERRÁNEO
Punta Quiviana
Fortín
La Restinga
Bocana
Zoco el Arbáa
Pozo
Jaimas
Casa del Santón de la Puntilla
MAR CHICA
Atalayón
Mayen Moh-Brahim
Pozos de Aograz
QUEBDANA
M. Tauima
Río Tigaud ó de Zeluan
R. del Caballo
GUENÁUA
M. Afra
Hasao
M. Hasao
Zoco el Telatza
Zoco el Jemis
Alcazaba de Zeluan
Amis
M. Axara
Al Axara
-BU-IFROR

ZOCO EL HAD.
REDOUBT FOR 2 COMPANIES.



D EL HAD.
FOR 2 COMPANIES.

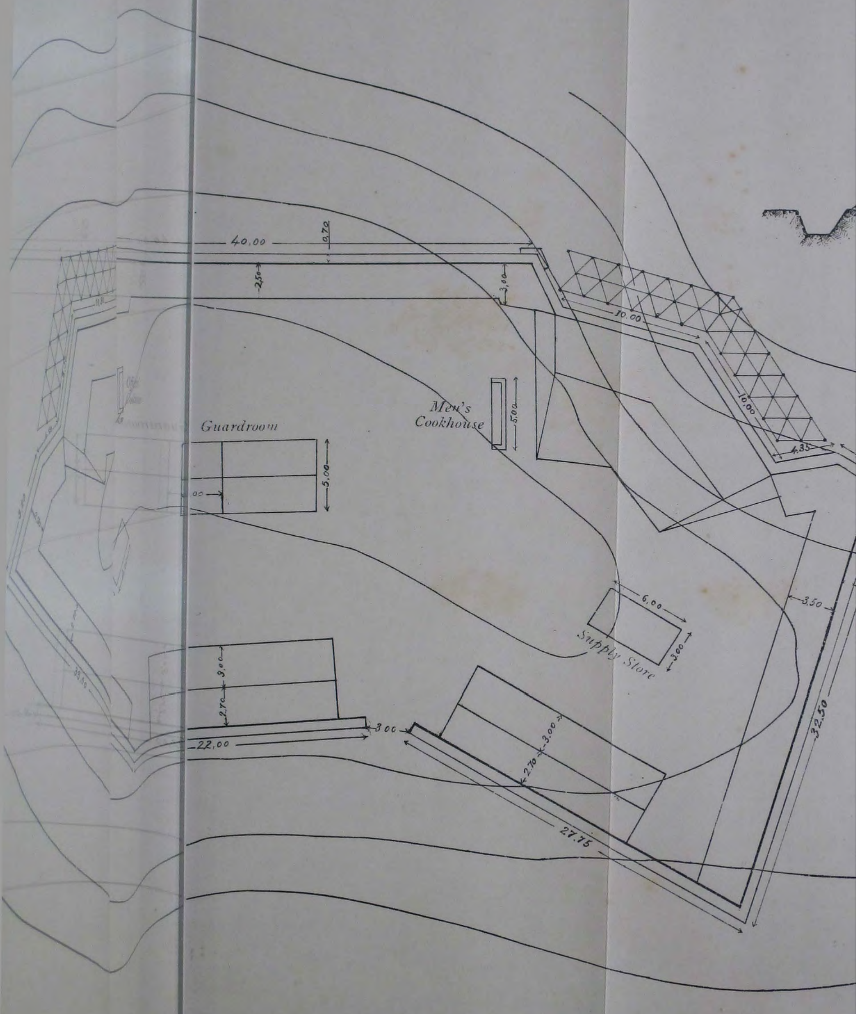
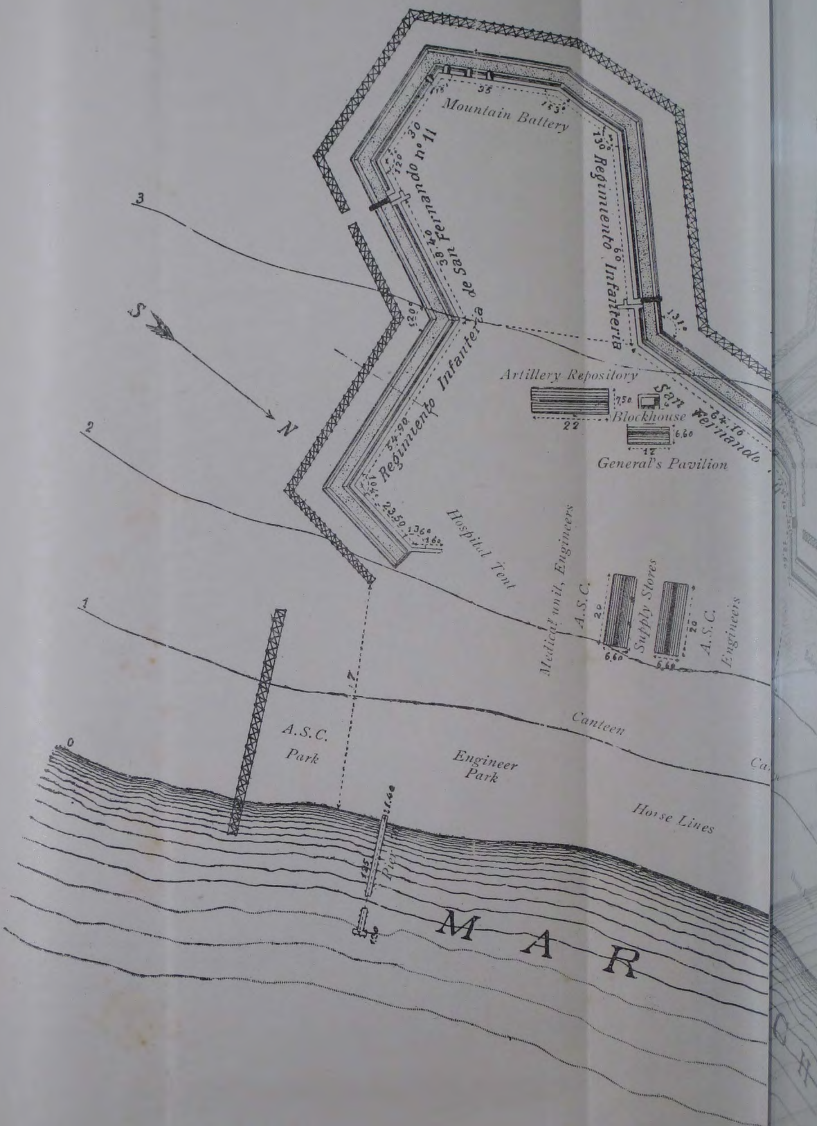


PLATE XXVIII.

POSITION OF NADOR & MONTE ARBÓS.



Mountain Battery
Regimiento Infanteria de San Fernando nº 11
13º Regimiento Infanteria
San Fernando
Artillery Repository
Blockhouse
General's Pavilion
Hospital Tent
Medical unit, Engineers
A.S.C.
Supply Stores
A.S.C.
Engineers
Canteen
A.S.C.
Park
Engineer
Park
Horse Lines
Pier
M A R
S
N
3
2
1
0

PLATE XXIX.

REDOUBT OF NADOR.

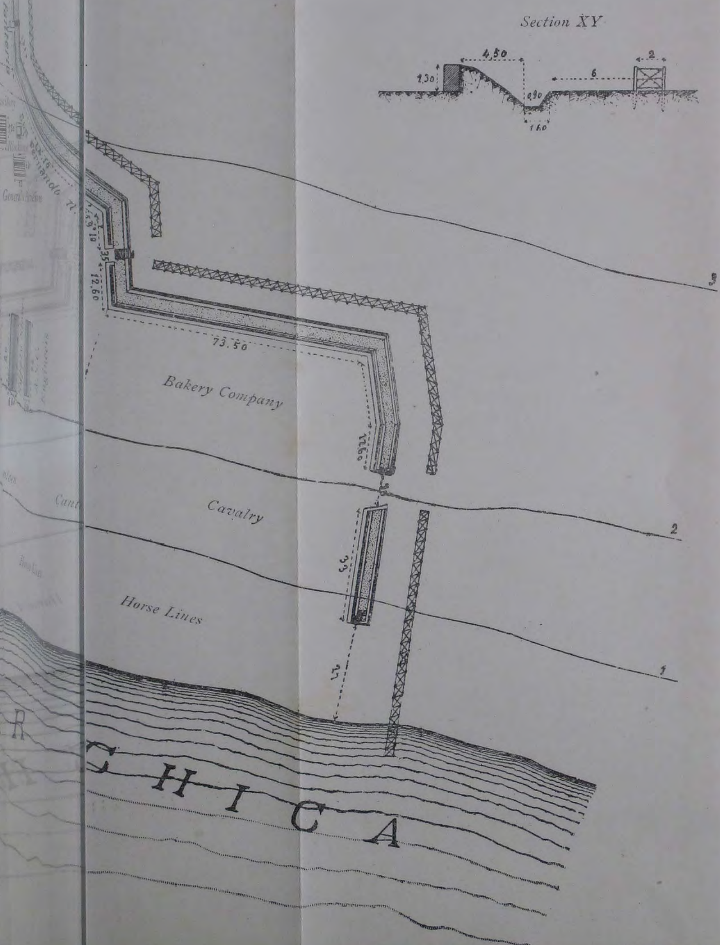


PLATE XXX.

REDOUBT FOR 2 COMPANIES & 4 SAINT-CHAMONT GUNS AT SEBT.

(Intermediate position on the road from Nador to Atlaten).

Scale 1 : 2.000.

Situation of the work.

a b c d Wire entanglement of two rows of pickets in front of the infantry firing line and of three rows in front of the artillery.

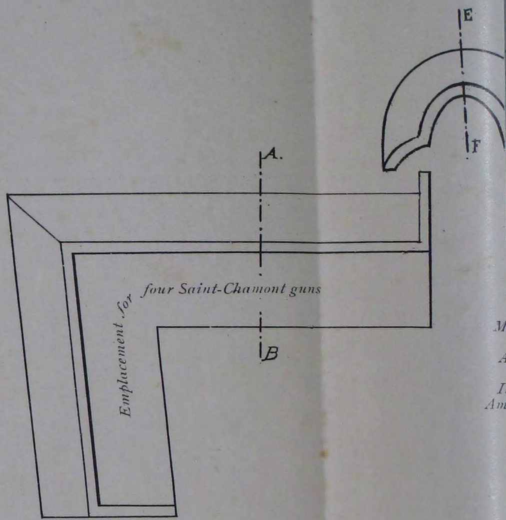
m n Entrenchment for infantry for the purpose of sweeping the dead ground on this front of the redoubt.

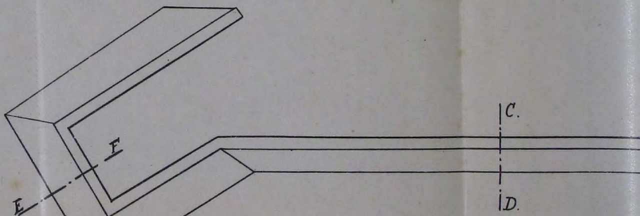
p q Entrenchment for infantry commanding *m n* and commanded from the redoubt.

r s Road which connects with the road from Nador.

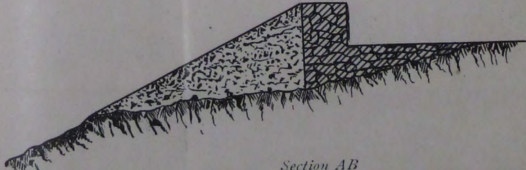
REDOUBT FOR 2 COMPANIES & 4 SAINT

(Intermediate position on the road f

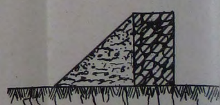




Scale 1 : 250



Section AB



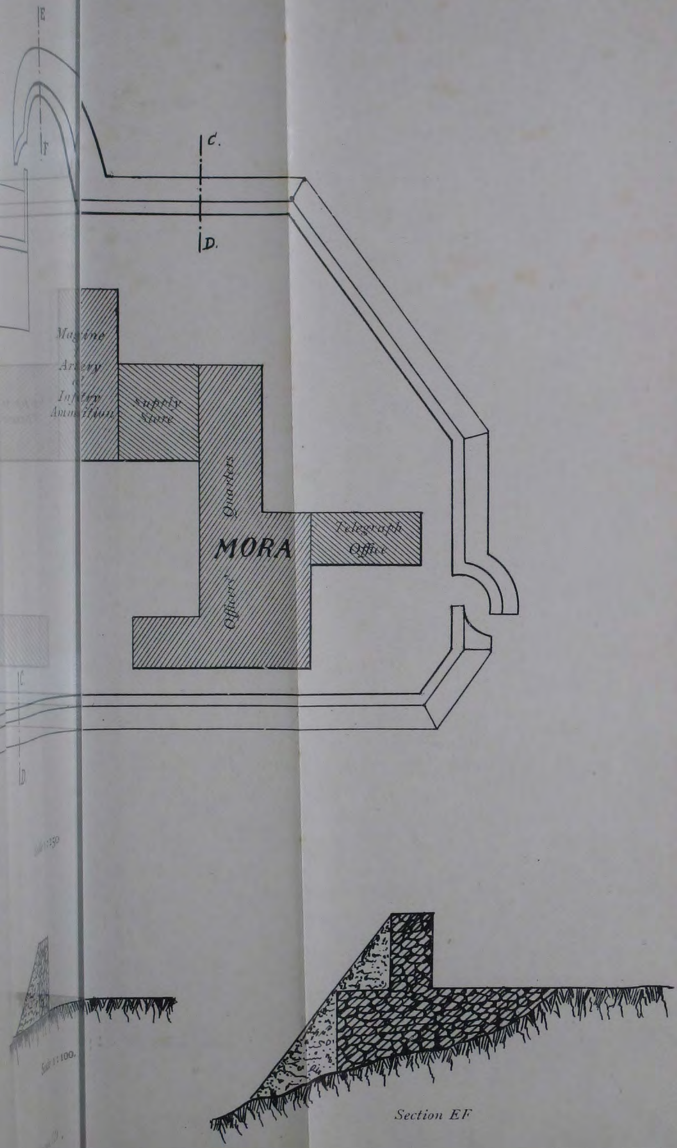
Scale 1 : 10

Section CD .

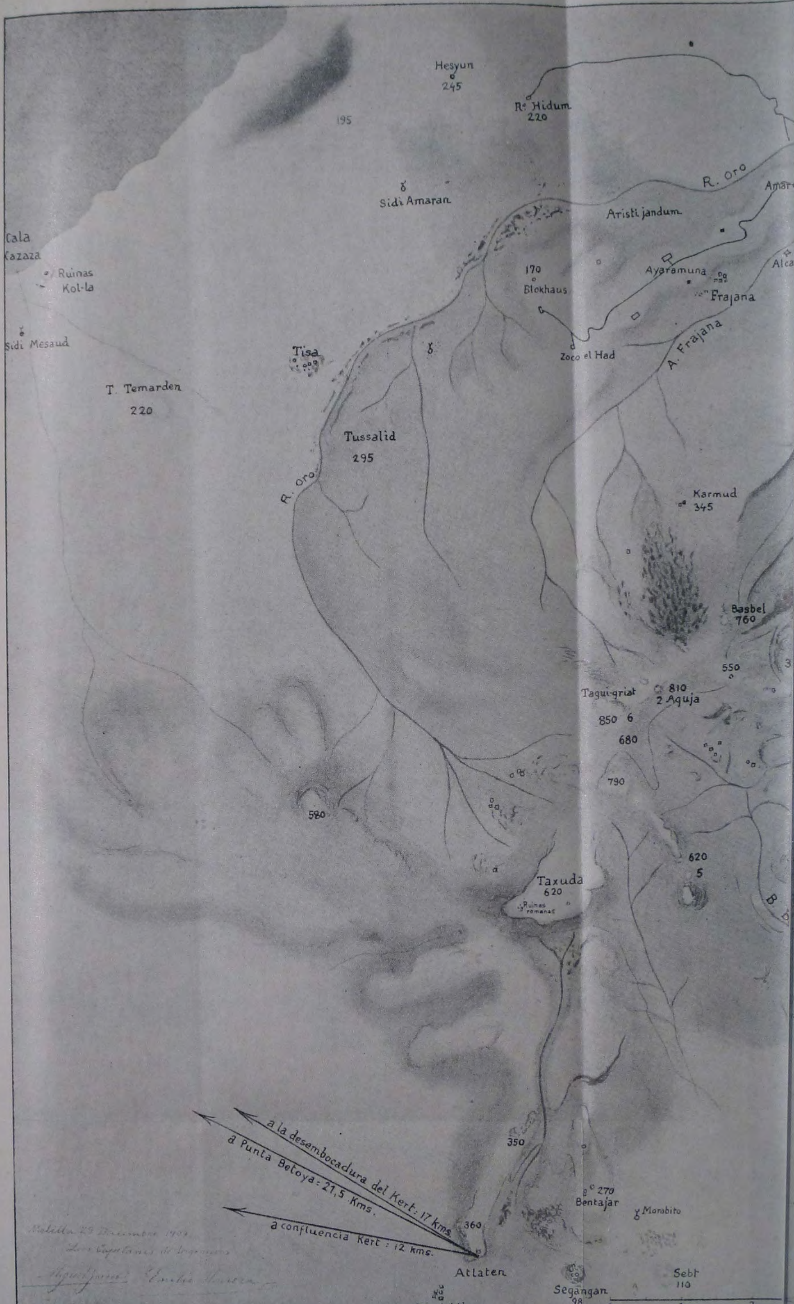
PLATE XXXI.

...PANIES & 4 SAINT-[illegible]AMONT GUNS AT SEBT.

(...osition on the road fro[illegible] Nador to Atlaten).

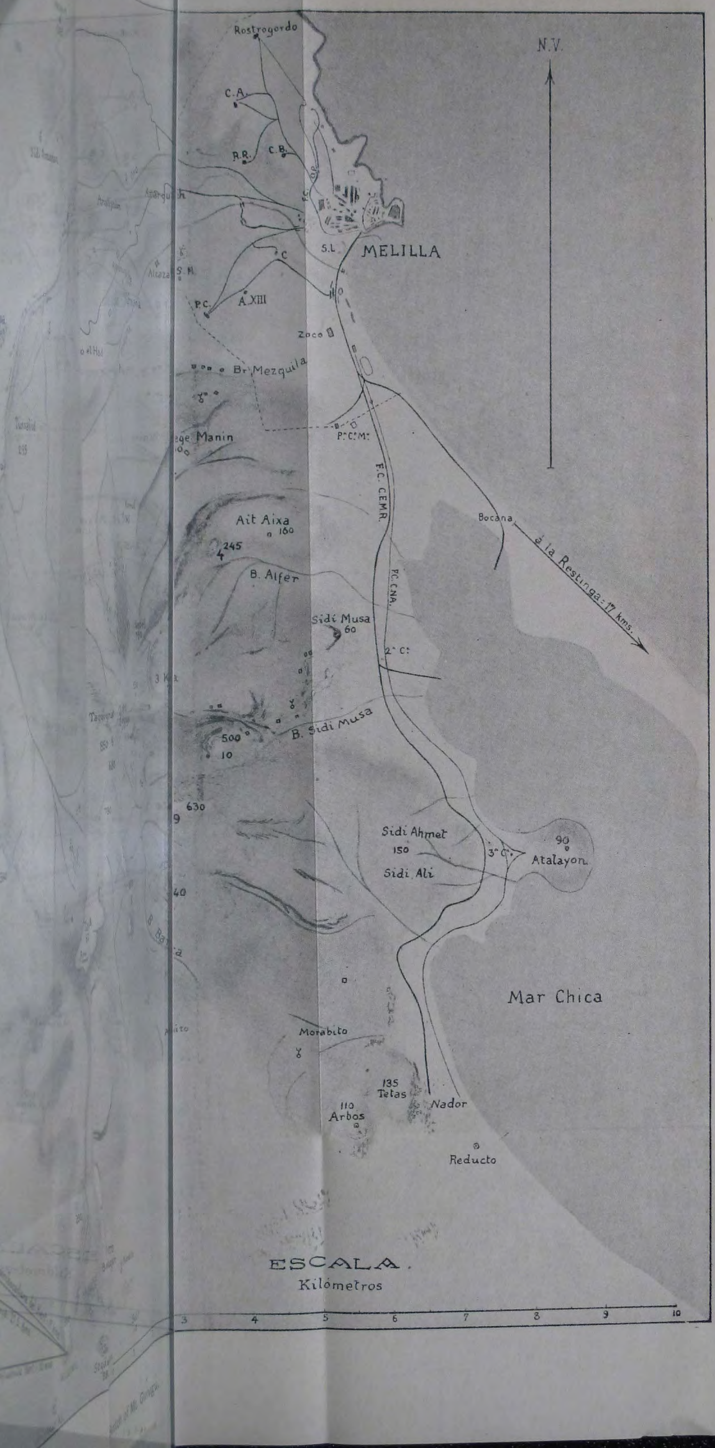


Section EF



Sketch of Mt. Gurugú.

PLATE XXXII.


N.V.
Rostrogordo
C.A.
R.R.
C.B.
F.C.
MELILLA
S.L.
C
S. N.
P.C.
A. XIII
Zoco
Br. Mezquita
P.C. M.
Manin
F.C. CEMR.
Bocana
á la Restinga: 17 kms.
Ait Aixa
160
245
B. Alfer
F.C. C.N.A.
Sidi Musa
60
2° C.
500
10
B. Sidi Musa
630
Sidi Ahmet
150
Sidi Ali
3° C.
90
Atalayon
Mar Chica
Morabito
135
Tetas
110
Arbos
Nador
Reducto
ESCALA.
Kilómetros
3
4
5
6
7
8
9
10

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WORKS ECONOMICS.

BY

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WORKS ECONOMICS.

THE Science of Engineering Economics, like the Science of War, is divided into two broad classes, like Strategy and Tactics, viz. :—The Economics of Policy, and the Economics of Practice. I do not propose in these lectures to say anything about the former, because it concerns the financier and the statesman rather than the engineer, also because the subject is too wide for a few lectures, even if I were capable of delivering them, and because the principles vary with each case. The principles of the Economics of Practice on the other hand are of universal application to all branches of engineering, they have their place in war as well as in peace.

This last may appear an unexpected statement because in war money is of secondary importance in the execution of works, and when we speak of economy our minds naturally think of money only. But engineering economy is not, primarily at least, a matter of money. We must not limit the consideration of this subject to financial regulations and to the audit of accounts. These regulations must necessarily be framed and observed, and audit of accounts is what every engineer must be ready to accept in fullest detail, but it is quite possible for all this to exist concurrently with reckless extravagance. The horses which draw the coach of engineering economics are the saving of labour, of time, of materials, and sometimes of human life, and if these are properly driven, economy in money will inevitably follow. It is true that in the purely financial aspect of engineering, much time and trouble may be saved by the observance of strict business methods, and it is also true that the cost of a work is a direct measure of its economy, so that by comparison of prices, which every engineer should habitually examine, the results of economy in design and execution can be relatively judged. In these lectures therefore the cost of various works will be constantly alluded to as a measure of economy.

The whole subject may be classified under five headings, under one or other of which all works economy will fall. These are :— 1. Planning. 2. Materials. 3. Structural Design. 4. Works Methods. 5. Contracts and Accounts. The order given is not necessarily that of relative importance, which indeed varies with circumstances, but it is the order in which usually the subject must be considered in any important public work, where one has first to consider how the various parts shall be most suitably arranged, then what materials shall be used, then what quantity of those materials is required, next how the work is to be built, and lastly how it is to be paid for.

In these lectures I shall endeavour to elucidate my description of these principles by referring to some works recently built, as examples only, not as models for imitation ; simply presented to you because they are an actual translation, into solid fact, of certain principles. They are in themselves of little importance except as illustrating principles, which are all important.

There is, however, one matter which must be dealt with first, it applies to every class of engineering and it underlies all the principles above enunciated. That is *efficiency*. No economy in connection with permanent work must be purchased at the cost of efficiency, for it will certainly result in increased expense in the long run. I could, if I had time, give you many instances to prove this, but I hardly think it is necessary to do so. Efficiency I would define as that which accomplishes, or assists in the accomplishment of, the main object for which the work is intended.

Every engineering work has some main object. A railway has for its object the transportation of passengers and goods in minimum time and at minimum cost in working. A coast battery is intended to defend by artillery fire the channels of approach to a harbour. A water supply scheme is intended to supply, at all times, given quantities of water at certain places. There may be secondary objects, sometimes of great importance, as a coast battery not only defends the approach channels, but also protects the gun detachments, guns, mountings, ammunition, etc., from hostile fire, a most important object, but secondary to the main object. Similarly there are buildings of an ornate or imposing character, in which architectural treatment is a most important object, but in most cases it is a secondary object when compared with the purpose of the building *e.g.* as a residence for a Governor, or for Divine worship. Any reduction of efficiency, either to suit architectural treatment, or because the work has to be ready in a great hurry, or for any other cause, is a false economy. We have to bear this great fact of efficiency continually in mind, and it especially concerns the first great principle, viz. :—

I. *Economy in Planning.*—This concerns the arrangements for the various parts of a work and the determination of the dimensions necessary to ensure efficiency, leaving a small margin for working when complete. This planning should involve consideration of the ultimate use of the work *e.g.* in the case of a workshop or factory one has to consider not merely the convenience of the workmen and the position of the machinery, but the ingress of raw material and the disposal of the finished articles. In the case of a water supply one has to consider the possibility of future extension, and the probability of temporary breakdown. In the cases with which we military engineers usually have to deal, *i.e.* the designs for fortifications and barracks, the necessary dimensions are generally supplied to us in the standard designs for defensive works, and the Barrack Synopsis, that useful compendium of information which deals with authorized allowances, based on experience for different classes of buildings. Where no previous guide of this description exists, we have to work from first principles, with efficiency as our golden rule. Once we know our dimensions, economy in planning consists in so arranging the component parts that, while efficiency is satisfied, everything redundant is reduced to a minimum. Economy begins when efficiency is met.

To take a simple case—a masonry road bridge where it is decided that two lines of carts may pass one another, *i.e.* with a road 16′ wide. Allowing $1\frac{1}{2}'$ for the width of parapet and curb on each side we get a total width of 19′, which apparently must be continued to the lower parts of the bridge, and be the minimum width of arches, spandrils, piers and foundations. Now, however, economy in planning takes up the running, and by corbelling for a foot on each side just below the level of the roadway reduces the lower thickness to 17′, without detriment to efficiency, but reducing the quantity of work, and the cost, by some 10 per cent.

It is of the utmost importance that the engineer who plans a work should, if possible, have some practical knowledge of the use to which the work is to be put, otherwise his planning may be very faulty. A railway should be planned by one who has some experience of open line maintenance and traffic working, an irrigation canal by a man who knows about the application of water to agriculture, a troop stable should be designed by an officer who knows something of the interior economy of mounted corps, and a barrack by one who knows the routine of a soldier's life. But if it should happen, as it often inevitably does happen, that the designer has not this working experience, he should consult, *at every stage of his plans*, those who do know. It is not sufficient to take the finished plans to the latter and ask for a signature. Men will be reluctant to alter materially a set of finished drawings which have involved time and labour.

During the Afghan War an instance occurred of waste of time and labour by not consulting officers of practical experience. A road had to be made, over a mountain pass, for siege artillery and elephants. The orders given by the C.R.E. were that a grade of 1 in 20 was to be adhered to, and consequently the road was laid out, strictly at that grade, but with many sharp zigzags. Before the guns came the road work was transferred to another officer, working under the C.R.E. Line of Communications—a man of much frontier war experience, who saw at a glance that sharp twists in a road were impossible for limbered guns, and consequently he laid out an entirely different line, much steeper than the first, but comparatively straight. When the artillery came they would not look at the first road, which for their purposes was useless. If in the first instance an artillery officer had been consulted he would at once have pointed out that a road with sharp turns is good enough for mules and mountain artillery but useless for elephants and heavy limbered guns.

In another case a young officer made a road for field guns only 6′ wide. This, with a width of track of 5′ 6″, left only 3″ margin on either side, which may be all very well at the Military Tournament at Olympia, but is not quite enough margin for a precipitous hillside. On the other hand I heard the other day of a military bridge at the Swiss manœuvres, which was 13′ wide. We all know that 10′ is an ample roadway for a military bridge, so that in this case there was a redundancy of 3′—labour and material wasted.

In barrack buildings, the usual redundancy is in passages, halls, and sometimes in the height of rooms. As a sample of economic planning let me show first a plan (*Plate* I., *Figs.* 1 and 2) of some married quarters, suitable for a country district, or a coast defence work, where there is plenty of fresh air (not suitable for a town and forbidden in its back-to-back plan by most building by-laws). The plan gives separate entrances to each quarter, brings the bedrooms into the interior and the sanitary conveniences into the angles. Every available space is utilized, and certain walls are common to two quarters. This costs about £160—£170 a quarter. Next let me show another block (*Plate* II.) rather more pleasing in external appearance and having cross ventilation. These cost about £200—£210 per quarter. The next illustration (*Plate* I., *Figs.* 3, 4, and 5) shows a row of standard design quarters (with two bedrooms each) where there is still more unoccupied space in staircase and roof bringing the cost per quarter up to about £300. In the first and second cases the economy is mainly by utilizing all available space for actual living rooms.

II. *Economy in Materials.*—It is evident that where the requirements of a case can be met by a cheap material, there is no reason to use one of a more costly nature. It will be readily agreed, also, that the character and position of a work govern the choice of material. A staircase of marble is suitable for the approach to a royal palace, but is out of place in a soldiers' barrack, and a better class of floor may be allowed for an officers' mess than would be suitable for a soldiers' recreation room. On such points nothing more need be said. But I wish to lay emphasis on the fact that nowadays there are many materials available for use which were unknown to our grandfathers, or even our fathers. Such are the many patent roof coverings, artificial stones, partitions, means of warming and lighting and above all cement and steel. Of the uses of the last two in connection with reinforced concrete it is unnecessary for me to dilate, for the subject is, I know, thoroughly considered in the course of studies in this School. I would, however, remind you that its use involves the closest supervision in execution as well as a sound knowledge of the theoretical principles underlying its use.

The use of steel and concrete in combination often renders possible work which otherwise could not be carried out except at prohibitive expense. To illustrate this I cannot do better than show a photograph of one among several similar bridges on the road between one of our Indian frontier garrisons and the foot of the mountains some 40 miles to the west (*Photo* 1). The mountains are inhabited by a turbulent tribe against whom it is sometimes necessary to send an armed force. The intervening country is a desert plain, furrowed with some 10 or 12 ravines of an average width of 100′ and depth 16′ to 20′. There is little cultivation on this plain, and few inhabitants, for water is scarce and bad. The rainfall is scanty but occasionally there are floods which make the ravines impassable for two or three days at a time. In a project for a road over this plain it was proposed to omit bridging the ravines altogether, on account of the expense of building the bridges, of the type usually adopted in that part of India, viz. :—brick piers with brick arches. For the bricks would have had to be brought from a great distance, there being no possibility of burning them near the bridge sites, and the task of supplying the workmen with food, shelter and water would so add to the cost as to make it out of the question. To omit the bridges entirely, however, would be, as you can see, to obviate the main purpose of the road, a loss of efficiency so great as to render it questionable whether it was worth making the remainder. A solution was found by using steel trestles, which could easily be made up at central workshops, and carted to the site. These could be founded on concrete blocks, for which gravel was procurable at the sites, and a few bags of cement could be sent out at the same time as the steel work. The number of workmen was thus reduced to a minimum, a mere fraction of what would be required for a brick bridge. I have no figures to show what the saving in money was, for I doubt if the cost of the brick bridges was ever worked out, but it was evidently a very substantial economy.

There is, in addition, one feature which is of great importance in this design. You will observe that we have not only, by the use of steel trestles, and struts, utilized material that is easily transported and easily erected, but we have substituted, for that which is theoretically uncertain, that which is definite and determinate. The planning of the steel members follows generally the theoretical lines of resistance in masonry arches and piers, with this important difference, that, whereas, with masonry, the actual stress on any given part is difficult to determine with any accuracy, there is no such uncertainty with the steel, each member of which can be exactly calculated. As the weight borne by the steel legs, and distributed over the concrete blocks at the base, would in the case of a brick pier be distributed, for practical reasons, over a much larger area of foundation, it follows that if the former is sufficient, the latter must be unnecessarily large for the work it has to perform.

It is this principle that underlies all steel frame design, enabling the engineer to concentrate on certain pillars or stanchions the weight of roofing, floors, etc., and using the walls, as screens from weather only. This class of design is specially suited for barracks, and permanent camps, where there are numbers of long buildings with comparatively few cross walls, such as storehouses, stables, etc.

Before illustrating to you how this has been done in barracks, let me first show you (*Plate* III., *Figs.* 1, 2, and 3) a plan of the ordinary hut barrack, built in large numbers at the various hutted camps at our home stations (Bulford, Bordon, Blackdown, etc.). There may have been reasons, of which I am unaware, for building this type of hut, but regarded from a "Works Economics" point of view, it is very faulty. The walls and roof are of corrugated iron, a material which in itself is objectionable, both because it needs periodical painting, and also because it is unsuited for dwellings in this climate, being hot in summer and cold in winter. The walls, borne on a framework of wood, and the floors carried on joists, are supported on dwarf walls of brick with concrete foundations, all of which, for practical reasons are far larger than is necessary to support the weight of walls and floors, and they yet do nothing to increase the comfort of the inhabitants.

In place of this I show the plan of another hut (*Plate* IV., *Figs.* 1 to 4) which costs practically the same, but built on the steel frame plan. The weight of the roof trusses, arranged at 10′ intervals, is borne directly by steel stanchions, which also take the weight of the soldiers' cupboards, and, by means of a little cross framing, the windows. The floor is solid, and the foundations of the building are mainly concentrated at the stanchions. The exterior of the walls, which are only half a brick thick, are rough cast and the interior is plastered. Some barracks built on this type have stood the test of two winters, and have been found as warm and comfortable as could reasonably be desired, while the cost—£20 per man—is just half that of those on the standard design, as built at Tidworth, the Curragh, etc. The photograph (*Photo* 2) shows that the external appearance is not objectionable.

The same principle has been applied to barracks of two stories, where the upright stanchions carry cross girders supporting the upper floor, as well as the roof, etc. (*Plate* V., *Figs.* 1 to 3, and *Plate* VI., *Figs.* 1 to 5).

This class of construction is not so suitable to buildings divided

Photo 1.—Trestle Bridge.

Photo 2.—R.E. Barracks, Bordon.—Outside of One Barrack Block.

into a number of small rooms, as in officers' quarters or married soldiers' quarters, because in these the cross walls may be utilized for the weights of roofs and floors.

We now come to the third main heading.

III. *Economy in Structural Design.*—This may be said to embrace the entire Science of Applied Mechanics, and as this is already a subject of instruction at the S.M.E. I only propose to touch on a few practical applications. Its aim is so to arrange material in a design that while sufficient to meet all the needs of the case, it shall be the least in quantity, and so disposed as to utilize in the best way its specific qualities. But Applied Mechanics, valuable and indeed indispensable as it is, has certain very definite limitations. It cannot tell, for instance, the cost of various modes of workmanship, and thus it may happen that a solution of a problem which gives a minimum of material may result in more expensive work than one where rather more of the same material, but worked in a different manner, is used. A steel roof, for instance, of 50′ span can be designed with tie rods of round bars, struts of double flat bars, and pin and link joints, and science may probably tell us that this involves a minimum of material. Practice however steps in and says that steel is difficult to forge, and that the true bearing of links and pins is fitters' work of a somewhat costly nature. Hence it would be cheaper to use flat tension bars, with angle irons for struts, and riveted joints, even though these may involve rather more actual material, and rather less scientific arrangement. Similarly, in a piped water supply to a group of buildings, it may be better to have a few standard sizes of pipes, even though these may be larger than is scientifically necessary, rather than risk confusion on the part of workmen, and extra charges from manufacturers owing to differences in sizes and patterns.

Again, the limitations of Applied Mechanics are most conspicuous when we deal with what I may call the attacking forces *e.g.* the action of wind, pressure of earth and the like. Much of this is being gradually elucidated by careful experiment, for instance we now know a great deal more about the flow of water in pipes and channels than we did 30 or 40 years ago, and the views of wind pressure on roofs, held as gospel at that period have recently been wholly revolutionized. While experimental science is in this state of interrogation we need to be careful lest we assume, for the foundation of our calculations, that which is as yet a matter of question. We have, however, so large a field of certainties that we can in most cases go forward with confidence utilizing the results of recent experiments to correct old-fashioned practice.

It is a wholesome rule in India, one which might well be adopted in our home procedure, that with every scheme, great or small, there should be a sheet of calculations.

I shall now allude to a few actual cases.

It has been stated above that the system of steel skeleton construction was specially suitable to military buildings, such as stables, storehouses, riding schools, gymnasia, etc., where the length of the building is necessarily great compared with the width, and where no cross walls are possible. The advantages of steel stanchions in such cases are twofold, viz. :—they support the upper weight, concentrating it on definite foundations, and they act as stiffeners to the main walls. One can see how the latter function is performed, if we consider the case of a high enclosure wall of the ordinary thickness of brickwork, say 14″ or 18″. If the wall is exposed to wind, as it usually is, the moment of overturning force will be far greater than the moment of stability, and hence for equilibrium the wall depends on the strength, or rather the adhesion, of the mortar in the lower courses of brickwork. As this rarely exceeds 40 lbs. per square inch, it is customary in brick walls to stiffen the whole by buttresses at regular intervals. If however steel stanchions are introduced, the ultimate tensile strength of steel being 32 tons per square inch, it is evident that not only no buttresses are required, but that a far thinner wall would effect the purpose equally well. This principle may be applied to the long buildings alluded to above. Where there are cross walls these act as buttresses. Where there are no cross walls for considerable lengths, the effect of steel stanchions is to stiffen the whole and enable a relatively thin wall to be safe.

In the case of such stables as those shown in *Photos* 3 and 4 the worst conditions would be when all the windows on one side are open and those on the other side shut. It is conceivable that in a severe gale, the wind pressure blowing in through the open windows, and unable to escape might act like a fluid pressing in all directions, neutralizing the weight of the roof and tending to thrust the walls outwards. I think it will be found that the steel stanchions, regarded as cantilevers, under such conditions, have ample strength, even without taking the resistance of the intervening walls into account. It will be observed that midway between each pair of stanchions, there is a vertical angle iron designed to take the weight of the manger, bail and window, which of course adds appreciably to the stability and stiffness of the walls. Further increase in stability is added by the harness rooms, litter sheds, etc., and by the brackets connecting the stanchions to the trusses. It is therefore theoretically unnecessary (though desirable for the practical purpose of enclosing the steel in brickwork) to add buttresses at the stanchions.

Before leaving the design of these stables I would call attention to the roof. This is a king post truss of 32′ span, at 11′ intervals, with a series of purlins along the principal rafter, which is thus brought under combined transverse and compressive stress, and has to be calculated accordingly. The scantlings of all the roof members are really more than sufficient, with an ample margin of safety, for the

Photo 3.—A.S.C. Stables, Aldershot.

Photo 4.—A.S.C. Stables, Aldershot.

weight to be borne, and yet they are much lighter than those laid down in the usual pocket-book tables for a timber roof of 30′ span, at 10′ intervals. Had the latter been taken, there would have been one central purlin and a pole plate with common rafters at 12″ intervals, and in each bay this construction would have resulted in some 28 or 29 cubic feet of material more than has actually been adopted. The cost of this, at Aldershot prices, would have been about £4, and as each bay covers four stalls, this would have been an extra cost of £1 per horse. This is an inappreciable sum if one is building a stable for only a few horses, but with the large stables which we have to build (there are over 20,000 horses in the British Army) the economy—obtained by five minutes' calculation—may be very substantial. This is a fair example of the disadvantage arising from indiscriminate use of pocket-book tables, many of which are based on Tredgold's treatise written nearly 100 years ago. I venture to say that owing to the want of a little application of theory, on the part of builders and architects, there is an enormous amount of waste in civil practice. The illustration afforded by the stable roof in this case shows how important this matter of simple calculation is in connection with barracks where the same building may have to be repeated many times.

The cost of these stables now being built at Aldershot is about £28 a horse, and I think it may be possible still further to reduce this. As however a certain amount of Sapper labour is employed, it may be fair to put the contract price at about £32 to £35 per horse, or 4d. per foot-cube for the whole. A certain definite economy results from getting the joinery made up in the S.M.E. workshops. As regards the cost of similar stables in civil life, I quote the following from Mr. Coleman's book on Stable Construction :—"Third-class stables intended to accommodate large numbers of horses, and provided with swing bails or plain stall partitions, as for tramway and omnibus companies, etc., about £45 per horse." The same author in his book on Approximate Estimates gives the price of such stables as varying from £40 to £60 per horse. It may be noted, moreover, that carriers and omnibus companies rarely give more space than 1,000 cubic feet per horse, and do not supply harness rooms, whereas in the Aldershot stables we are allowing 1,600 cubic feet to each horse, and are providing all accessories in the way of forage stores, harness rooms, etc.

The system of steel frame construction is still more economical in open lofty buildings such as gymnasia and riding schools. *Plate* VII., *Figs.* 1, 2, and 3, show a large riding school recently built for the Cavalry School at Netheravon, 228′ long by 72′ wide, a description of which, as a riding school apart from technical details, has recently been given in *The Cavalry Journal*. The trusses in this building are placed at the somewhat unusual interval of 22′. This is done so as to reduce the number of trusses, which are necessarily costly, to a minimum. Between the trusses are braced steel purlins, or stringers, carrying an intermediate principal rafter, which supports wooden purlins in the usual way. There are brick buttresses surrounding the main stanchions calculated to resist the thrust produced by the expansion of the roof in hot weather. The cost of this building, including an installation of air gas, was £4,500, which works out to 2d. per foot-cube, or £20 per square (100′) of floor area. Comparing this with the cost of the riding schools built some 50 years ago in the Cavalry Barracks at Aldershot, it appears that the latter (with a floor area of 178′ × 53′) cost £63 per square. From this it appears that the steel frame principle at Netheravon has resulted in very substantial relative economy.

The concert hall recently built at Tidworth (*Photo* 5) is another example of the same class. The roof was designed three times before a satisfactory solution was attained, and the reason why a curved form was adopted was in order to give the occupants of the gallery an uninterrupted view of the stage. The cost per foot-cube in this building was 3½d.

One must not however jump to the conclusion that in all cases steel skeleton work is the cheapest form to be adopted. Where there are many small rooms and cross walls it is not usually the cheapest method.

IV. *Economy in Works Methods.*—This concerns not so much the permanent construction as the auxiliary and temporary methods by which work is carried into execution. Sometimes the matter may not be considered at all, at other times it is all-important and may entirely govern the permanent design. To illustrate my meaning I think I cannot do better than quote the case of some bridges on a road on the N.W. frontier of India. The road had necessarily to pass through a precipitous gorge about a mile long, of no great width, and it was necessary to have two bridges across the gorge at a considerable height, so as to be well above flood level. The sites of these bridges were about 90 miles from the nearest railway and the intervening road was only a camel track. There were practically no facilities at the site for sheltering workmen. The design of the bridges had therefore to be governed by the works methods, viz.:— The component parts had to be of such sizes and weights as could be carried on camels and easily erected. The photo (*Photo* 6 and 7) shows one of the bridges, it was rapidly put up and was relatively cheap.

In the construction of large bridges this question of economy in works methods concerns the local engineer far more than the design, in which usually he has no voice whatever. Whether the girders should be built on staging, or lifted from below, or rolled out from the ends, whether the river should be diverted, and how it should be

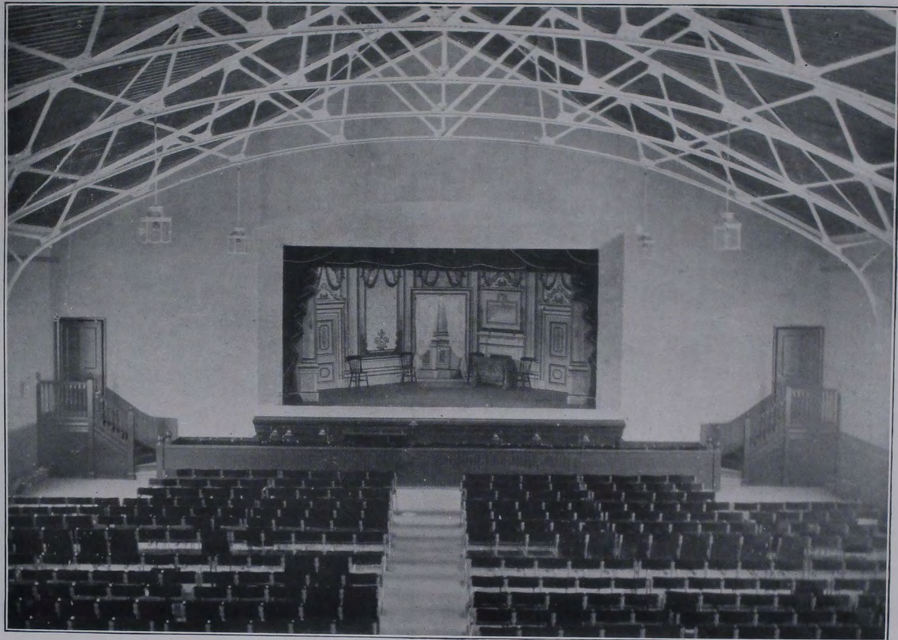

Photo 5.—Tidworth Concert Hall.

Photo 6.—Cantilever Bridge.

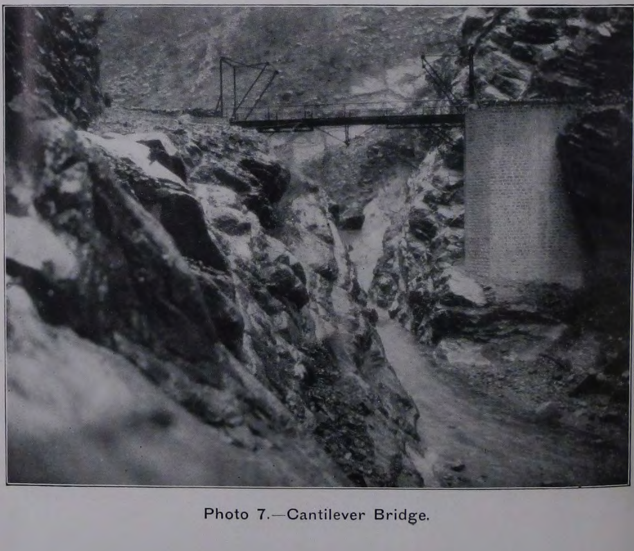

Photo 7.—Cantilever Bridge.

done, these and many other similar matters come within this category and whether they are well done or not, often just makes the difference between economy and extravagance on the work as a whole. In civilized countries these matters are usually entrusted to contractors and sometimes this may be done in distant lands also, but it is almost always costly and if the local engineer has a good head on his shoulders he can generally do the work more cheaply by direct labour. On the Sind-Peshin Railway working under special pressure of time, great risk of floods, and exceedingly trying climatic conditions, the cost of girder erection by contract was Rs.120 a ton. At Nowshera, near Peshawar, in 1902 the cost of similar work on the N.W. Railway, by contract, was, I believe, Rs.30 per ton, and yet at the same time, and under more difficult circumstances, the cost by direct labour on the Connaught Bridge over the Swat River at Chakdara was only Rs.6 (exclusive of the pay of the officer in charge, and of the office establishment and of much of the tools and plant employed). The officer in question—a subaltern in the Corps—was a man of singular practical talent, as well as high scientific knowledge, such as very few contractors possess.

If there should be a main work, with certain subsidiary works which must be executed as a preliminary to it, and if there be two agencies or contracts involved, it is most important to see that the subsidiary works are so complete that no claims in respect of delay can be urged in connection with the execution of the main work, otherwise there may be endless expense and litigation. Thus a coast battery may be so situated that roads and landing piers are necessary before the work on the battery can be put in hand. It is necessary to ensure that such roads, etc., are ready before the contract for the main work is started.

An interesting instance of economy in works methods was afforded by the reconstruction works following the Jamaica earthquake of 14th January, 1907, when in a few seconds, all the barracks and other military buildings at Up Park Camp, Kingston, were destroyed. It was of the utmost importance to rebuild them as soon as possible, so as to house the garrison who, of course, were without accommodation. The first thing to be done was to decide on the design of buildings suitable to resist earthquakes and hurricanes (the plan of one barrack being shown on *Plate* III., *Figs.* 4 and 5), then to decide what materials could be obtained locally, and what should be sent from England. As regards the design, it was decided to build a steel framework, arranged in definite sections, so as to admit of extension or reduction, by a section at a time, if thought necessary. Then it was decided that the only local materials that could possibly be used were the roof shingles, and ballast for concrete in walls and foundations. Everything else had to be sent from England both because all trade in the island had been dislocated by the earthquake, and accepted, as a rule, with demur. No details are asked, nor given. That estimate is the basis of allotment. In India the normal procedure is to submit a scheme for consideration, with outline plans and estimates based on some definite details, long before any question of inclusion in the Annual Budget is contemplated. If the scheme is accepted, it is accorded what is called "Administrative Sanction," but the estimate is not taken as the actual basis of allotment, nor as a rule is there any such allotment until the whole has been thrashed out in ample detail. I have known from 12 to 16 years elapse between the Administrative Sanction, and the actual allotment of funds with authority to begin the work. This has its disadvantages for changes of officers are frequent, and differences of opinion involving re-design of the whole work, are inevitable. But at least it ensures careful engineering consideration, and that makes for economy. The detailed plans and estimates must be submitted in such a form that they can be subjected to the most minute scrutiny by independent experts at headquarters.

The difference of procedure in respect of contracts is still more marked. In England, tenders based on bills of quantities and specifications, are invited from firms of proved capacity. These tenders are sent to the Director of Army Contracts, whose duties are by no means confined to works, and who is in touch with all legal questions in respect of such matters. The system is a very fair one, and it results in economy because of the competition in trade, and it does not result in bad work, if the executive officers see that the conditions of the contract are duly observed. In the case of a reasonable contractor it is possible by mutual co-operation to ensure a minimum of friction. But it does not give an officer direct responsibility for the choice of the contractor, and herein lies the main difference between the English and Indian systems. In India the executive officers call for tenders and give out the contracts, they decide whether work shall be done by contract at all, and to what extent it shall be employed, they alone decide what men shall be tried as contractors. This system has the great advantage of concentrating responsibility for execution as well as design upon local authorities and thus developing strong self-reliance, and, by taking account of personality, is applicable to war as well as to peace. Officers get to know and to trust certain contractors, and this mutual co-operation is often of the utmost value in war. A contractor who has worked in cordial unison with an officer will follow him even into an enemy's country. In the Afghan War this was very noticeable, and this campaign, in this respect, is most instructive, for a large number of roads, fortified posts, etc., were thus built. The system, however, has its disadvantages in limiting the field of selection of contractors, thereby discouraging competition. It is so largely dependent on the personal equation that it is hampered by a change of officers and in this country, with our system of government, it would be difficult of general application.

A few words about estimates. There are two opinions about these. One is that an estimate for works should be on such a liberal scale as to cover all possible contingencies, and thus obviate the necessity for revision and subsequent application for increased funds.

The other view of the case is that the estimate should endeavour to represent as accurately as possible the minimum figure at which the work with its contingent requirements can be properly executed. If, during the progress of it, unforeseen requirements arise, there should be no discredit in submitting a revised estimate and obtaining an increased grant. For, if a large margin is entered in the first instance and passed, it is a direct incentive to carelessness, and not only so, but an extravagant standard is insensibly set up, of far-reaching effect in future cases. In the most efficient public department in which I ever served, viz. :—the Irrigation Branch of the P.W.D. in India, it was always customary to scrutinize estimates most minutely, and to reduce them to the lowest limits consistent with efficiency. If afterwards it was found that for some good reason, a revised estimate was necessary, it was regarded as the right course to adopt. The result was that work was always cheap, and generally very good.

* In respect of the obtaining of manufactured articles, the English system of having special contracts with specified firms for certain periods, is very good and most economical. Executive officers can, indeed they must, order their requirements direct from these firms and obtain the advantage of the low contract prices. It is an excellent system also for officers serving abroad for they can obtain what they want with the help of the inspecting staff at the War Office, at the times they require the articles, without having to foretell their needs long beforehand. In India the system is one that every engineer abhors, as giving a maximum of trouble with a minimum of useful result. It consists in sending in indents a year beforehand to the India Office, supported by a certificate from the Finance Branch that funds are available. This last proviso limits the field of action, and as for the other, it results in vague requisitions being sent in, for no engineer is possessed of prophetic powers and it is impossible to foretell, in very many important cases, what will be required 18 months or more, ahead. The result is that stores that are really needed are too frequently omitted and the actual stores obtained are often not used. This system is not only uneconomical, but it retards the progress of engineering.

I have now come to the end of my subject and would say a few

* This paragraph was omitted from the lecture, on account of pressure of time.

words in conclusion to my younger brother officers. The amount of public money that is entrusted annually to R.E. officers for expenditure on works in connection with the War Department, the Government of India, and in Egypt and the Soudan is not less than three millions sterling. It is an honourable and dignified task that is thus entrusted to us, and for the most part, it is committed to us with implicit confidence in our professional ability as well as our financial integrity. It is surely no unworthy study that we should endeavour to ascertain how to discharge this trust in the best possible way. I have endeavoured to place before you principles of universal application, which, if followed, are bound to result in economy, and the few examples I have quoted have, I think, proved that such economy may be of the most substantial proportions, and of the most far-reaching character. It will probably be within the reach of all of you to effect economies far in excess of your salaries, by personal attention to these details and principles, and thus you will repay the cost of that technical training which you are now receiving at the public expense. Possibly the results may not be fully appreciated by those under whom you serve, possibly no personal reward may be given to you—no brevet of promotion, or ribbon on your uniform. It is possible also that some comrade who has not worked at these matters may, for other reasons, be promoted before you, and you may therefore be tempted to think that your labour is in vain. You are at all events free from the temptation *not* to economize, which must be so potent when a man's livelihood depends on a percentage of his expenditure, or on the length of time taken to execute a definite task. But, gentlemen, the noble tradition of our Corps has always been that duty to King and country is put in the first place, irrespective of personal reward. The officer who plays for his own advantage is justly regarded as an outsider. If we were to name one quality which more than any other has been the distinguishing characteristic, among great variety of temperament and opportunity, of those illustrious men whose portraits adorn our beautiful Headquarter Mess, it would be I think, disinterested devotion to duty and utter disregard of personal reward. It was certainly so with those whose statues you pass every time you enter this building :—Burgoyne and Gordon. But while I would place before you as worthy of emulation the traditions of the past, let me briefly, in conclusion, give just one example, out of many, of what is going on in the present. Duty took me about a year ago, to the Soudan and there I was at many places warmly welcomed by brother officers whom it had been my duty to instruct when, some 15 or 16 years ago, I was on the Staff of the S.M.E. I found at least six of them each at the head of some great department of the State, administering large sums of public money, in the interests of the people, and in the development of a land, which at the time they were undergoing instruction here, was groaning under the unspeakable tyranny of the Khalifa. To-day the work of civilization, begun by Gordon and resumed by Kitchener, is being admirably carried on by officers of the same corps, a vigorous and capable band of young men, unostentatiously doing their duty and affording to the people of that land a striking example of good work and upright administration.

To you, gentlemen, may be in like manner similar opportunities given of translating to the people of distant lands, where jobbery and corruption are always associated with native administration, those lofty principles of financial purity which are the priceless heritage of our country, learnt in the first instance from the Gospel of Christ, and associated everywhere with the character of English gentlemen.

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Moving Loads on Military Bridges.

With some Notes on the

Graphical Representation of Formulæ.

BY

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MOVING LOADS ON MILITARY BRIDGES.

WITH SOME NOTES ON THE

GRAPHICAL REPRESENTATION OF FORMULÆ.

Moving Loads on Military Bridges.

THE traffic load on all bridges can be represented as consisting either of a distributed load, or of a series of concentrated loads, spaced at various distances apart.

From the point of view of the "road-bearer" group of bridge members, an aspect to which the present paper will be confined, the smaller the ratio of the spacing of these concentrated loads to the length of the span, the more nearly can they be considered as together forming a distributed load.

In the case of military bridges, where the road-bearers as a rule are not very long, it is usual to treat the load of a column of infantry or cavalry as a distributed load, but to deal with guns or wagons as a series of concentrated loads.

When the load can be taken as distributed, the calculations for determining the necessary strength of the road-bearers are simple, because the load can be considered to be uniform and continuous across the span.

In the case of other classes of bridge members, the possibility of partial loading may largely influence the design; for example, a suspension bridge is distorted by a partial load, and not by one covering the whole span. Even with the type of bridge member within the scope of this paper, the effects of an unequal loading may have to be taken into account; the stresses in certain bars of a fully loaded girder may be reversed when only a part of it is loaded. But as far as the transverse stress is concerned, and this stress alone will be considered here, the worst effect is obtained when the load covers the whole span.

It may be assumed moreover, that the road-bearers are supported only, and not fixed, at their ends.

On the other hand, it is usual to multiply the actual weight of the load by some factor, to allow for the moving nature of the load.

This is known as converting a "live load" to an "equivalent dead load," and the factor generally used is 3/2.

With the above limitations, it is well known that the greatest bending moment with uniform continuous load, or M_{ff} in the usual notation, occurs at the centre, and is equal to,

$$\frac{wL^2}{8} \quad \text{.................................(A)}$$

where w is the equivalent dead load per unit of length, and L is the span.

The case of a series of concentrated loads cannot be dismissed so readily. If the positions at any instant of a number of such loads on a given span are known, it is comparatively easy to work out the magnitude of the bending moment at any selected point. But as these loads, that are supposed to be connected together in some way, move across the span, the magnitude of the bending moment at this point is continually changing.

To determine the range of bending moments analytically, in order to find the maximum values at a succession of points across the span, would be so laborious as to be impracticable. There is a well-known graphical method of doing this by means of a series of parabolas ; it is somewhat operose, and the accuracy of the results depends very largely upon good draughtsmanship.

This, or some similar method, is occasionally made the basis of a substitution of an equivalent distributed load for the series of concentrated loads, a substitution that once tabulated for any given arrangement of loads, saves a great deal of subsequent calculation.*

In civil practice, the determination of the maximum value of the M_f at different points, by some such method as the foregoing, is necessary, because it is both practicable and economical to alter the cross-section of the bridge member in accordance with these varying values ; as a rule, moreover, there is plenty of time in which these calculations can be made.

In bridges built under military conditions, and with any materials that may be available, it is almost invariably not possible to alter the cross-section of the road-bearers in conformity with the value of the maximum M_f at different points throughout their length, and indeed there is generally no time available to make the necessary calculations ; this cross-section therefore remains constant, or possibly varies slightly, as in the case of a tapering spar. An obvious exception to this is the pontoon baulk, whose cross-section is modified, for economy of weight.

* See "Moving Loads on Railway Underbridges," by W. B. Farr, Assoc. M. Inst. C.E., *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CXLI., p. 2.

In general, however, the cross-section of the road-bearers of military bridges can be considered invariable, and therefore it is only necessary to discover the magnitude of the greatest of these maximum bending moments, usually denoted by the symbol M_{fff}; the actual position at which this maximum moment occurs is not even really important.

It will now be shown that this amount of information can be obtained very readily by analytical methods. For this purpose the following cases of moving concentrated loads will be considered :—

1. One load.
2. Two loads.
3. Three or more loads.

When one load is moving across a span, it is well known that the M_{fff} occurs under that load when it arrives at the centre of the span, and that it is then equal to

$$\frac{WL}{4} \quad \ldots\ldots (B)$$

where L as before is the span, and W the load, converted as usual to an equivalent dead load.

In the case of two loads, let them be W_1 and W_2, W_1 being the heavier, and let their distance apart be A_2, the length of the span being L, as shown in *Fig.* 1.

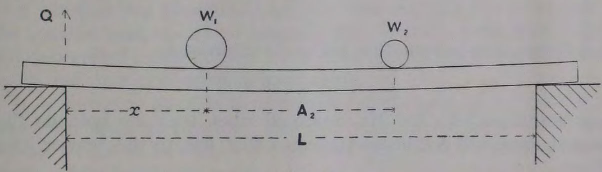


FIG. 1.

As there are only two loads, it is clear that any relative position they can assume on the span can be reversed, and therefore that the M_{fff} will occur under the heavier load, when it is at some point as yet undetermined.

When W_1 is at a distance, x, from one support say the left-hand one, the reaction at that support is,

$$Q = W_1 \frac{L-x}{L} + W_2 \frac{L-x-A_2}{L}$$

which can be written,

$$\frac{W_1+W_2}{L}\left\{L - x - \frac{W_2 A_2}{W_1+W_2}\right\}$$

The M_f under W_1 in this position is,

$$Qx = \frac{W_1 + W_2}{L}\left\{L - x - \frac{W_2 A_2}{W_1 + W_2}\right\} x$$

To find when this is a maximum, differentiate with respect to x. This gives,

$$X = \tfrac{1}{2}\left\{L - \frac{W_2 A_2}{W_1 + W_2}\right\} \quad \text{.........................(C)}$$

and the expression for the M_{fff} can be written,

$$\frac{W_1 + W_2}{L} \cdot X^2 \quad \text{............................(D)}$$

If the ratio of the heavier to the other load be such that,

$$W_1 = RW_2$$

and the ratio of their distance apart to the span such that,

$$A_2 = KL$$

it will be found that the value of the M_{fff} can be written,

$$\frac{W_1 L}{4}\left\{1 + \frac{K^2 - (R+1)(2K-1)}{R(R+1)}\right\}$$

The load W_1 alone, at the centre of the span, would produce an M_{fff}

$$\frac{W_1 L}{4}$$

It will therefore be seen, that unless the expression

$$K^2 - (R+1)(2K-1)$$

is greater than zero, the M_{fff} produced when they are both on the span at once, will not be greater than that due to the heavier load alone.

When the above expression is equal to zero, a critical value of K is obtained, given by,

$$K = R + 1 - \sqrt{R^2 + R}$$

in which case there are alternative positions of W_1, giving equal values of M_{fff}, one when acting alone, and one in conjunction with W_2. This value of K varies from nearly ·59 when the two loads are equal, to ·50, when one is infinitely greater than the other.

The case of two loads can therefore be summed up as follows. When the ratio, K, of the distance apart of the loads to the span, exceeds a certain value given by,

$$R + 1 - \sqrt{R^2 + R}$$

(R being the ratio of the heavier to the other load), the M_{fff} will occur under the heavier load when it arrives at the centre of the span. In other cases, the M_{fff} will occur under the heavier load when it is at a distance from the nearer support given by,

$$X=\frac{1}{2}\left\{L-\frac{W_2A_2}{W_1+W_2}\right\}$$

From the form of this expression for X, it follows that the heavier load, and the centre of gravity of the two loads, are at equal distances from the respective supports.

It will be seen that this is a more general statement of the rule given in *Military Engineering*, Part III., para. 10. In order to save the arithmetical labour of calculating the values of R and K, a graphical chart for determining the "critical span" is given at the end of this paper, in *Plate* I.

One point may be noticed in connection with this case of two loads. It is frequently supposed, with two equal loads whose distance apart, compared to the span, is less than the critical amount, that the M_{fff} will occur when they are symmetrically situated on the span. That this is not true will be seen from what has gone before, there being on the other hand, two positions giving the maximum value, namely when either load is at a distance from one support equal to the distance of the centre of gravity of the two loads from the other support.

When the series consists of three or more concentrated loads, it is not possible to give such a simple solution as when there are only two. It does not necessarily happen that the M_{fff} will occur under the heaviest load, though of course it must be under some load. The problem entirely depends on the mutual proportions of the several loads, and their respective distance apart.

It is however possible to state the general case of n loads on a supported beam as follows. The proof is given in Appendix I., but it may be stated here that the method employed is an extension of that used for two loads.

Let $W_1, W_2, \ldots W_p, \ldots W_n$, be the n loads, and let $A_1, A_2, \ldots A_p, \ldots A_n$, be the respective distances of the loads from W_1, the left-hand load; A_1 is of course equal to zero. Let x be the distance of the left-hand load from the left-hand support, and let L be the length of the span, as shown in *Fig.* 2.

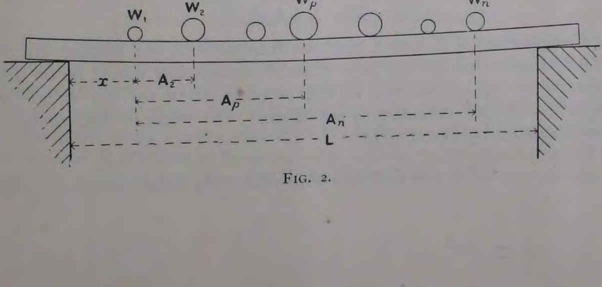


FIG. 2.

Then the bending moment under the pth load, W_p, will be greatest when

$$x = X_p = \tfrac{1}{2}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} - A_p\right\} \text{ .... (E)}$$

and will then be

$$\frac{\Sigma_1^n W}{4L}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} + A_p\right\}^2 + \Sigma_1^{p-1} WA - A_p \Sigma_1^{p-1} W \text{ ......(F)}$$

These formulæ are more complicated in appearance than they will be found to be in practice, but a few notes on the method of using them may be useful; the formulæ for one and two loads can also conveniently be considered at the same time.

With a given series of concentrated loads, and a comparatively small span, the first problem is whether the M_{fff} will be produced by one load at the centre of the span, or by two of the loads in conjunction. For this purpose the heaviest of the concentrated loads must be taken with the load that is nearest to it, and the critical span worked out, by arithmetic, or by the use of the chart already referred to. Assume in the first place that the span in question proves to be less than the critical one; it is obvious than no other single load at the centre can produce a greater M_{fff} than that produced by the heaviest in this position, but it is possible that two other loads together might do so; such a point depends upon the mutual proportions and distances of the loads, and no general rule can be laid down; an inspection of the conditions of any individual case, with a certain amount of experience, can alone decide whether or not it is worth while calculating the M_{fff} produced by any other pair of loads.

Now suppose that the span in question is greater than the critical span for the heaviest load and the load nearest to it. The formulæ for two loads must be used, for any pair likely to produce the M_{fff}. Here again no general rule can be given, but it will be found in the great majority of cases, that the predominating pair will consist of the heaviest load and one of those next to it, noticing that though one of these may be smaller than the other, the disparity may be counterbalanced by a greater proximity to the heaviest load; it may be necessary to consider both pairs.

The value of X must first be calculated by formula (C) and the value of Y also noted, where Y is,

$$L - (X + A_2)^*$$

These values of X and Y must be inspected to see whether either of the loads next to the pair under consideration would be on the span when the series was in the position given by the value for X or Y. If this inspection is satisfactory, the value of M_{fff} can now be calculated by formula (D).

* In the general case, $Y_p = L - (X_p + A_n)$.

If the values of X or Y show that other loads would be on the span, it is useless to work out the value of the M_{fff} for this pair, and it is then necessary to consider three or more of the loads; even when these values show a clear span, the case of three loads may sometimes also require calculation, because it is obvious that the formulæ can only take into account the data substituted in the general form, and cannot therefore be cognisant of contiguous, though unexpressed, loads. It is quite conceivable that two loads could assume a perfectly possible position for producing an M_{fff}, and yet that a greater M_{fff} might be caused by three loads.

Proceeding to the case of three or more loads, one of them must be selected and the value of X_p obtained by formula (E), that of Y_p being deduced from it. These values must be inspected as before, with this addition, that a negative value of either would show that one or more of the outer loads would be off the span. These must be removed from the series under consideration, and the values of X_p and Y_p re-determined. The value of the M_{fff} under the selected load can now be calculated by formula (F), and compared if necessary with that obtained for any other portion of the series.

Strictly speaking, the value of the M_{fff} for every load should be worked out, and the greatest finally selected, but it will be found, unless the mutual relationship of the series is very abnormal, that the greatest M_{fff} will occur under the heaviest load.

This explanation will be easier to follow if a numerical example be given. Suppose the span to be $22'$, and the load to be a number of typical heavy touring motor cars in single file. The arrangement of the loads, and their amounts, converted to equivalent dead loads in lbs., can be represented as in *Fig.* 3.

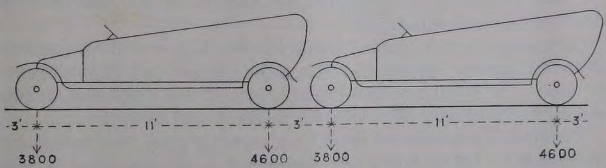


FIG. 3.

Consider the pair of loads representing the front wheels of one car, and the hind wheels of the next one. Their distance apart is $3'$, and the loads are respectively 4,600 and 3,800 lbs. The critical span will be found to be about $5'\ 2''$, though in the present case it is obvious that a single load would be out of the question.

Taking an inch as the unit of length, L is 264, and A_2 is 36. W_2A_2 will be found to be 136800, and $W_1 + W_2$ is 8400. From formula (C) the value of X is found to be about $124''$, and consequently Y is about $104''$. A reference to *Fig.* 3 will show that this is a possible position, though some of the other loads are very nearly on the span, showing that the case of three or more loads will have to be considered. From formula (D), by substituting this value of X, the M_{fff} will be found to be about 489,200 inch-lbs.

Now take one car on the span, with the front wheels of the car behind; let the hind wheels be taken as the selected load, W_p. The data may be tabulated as follows :—

$$W_1 = 3800 \quad A_1 = 0 \quad W_1A_1 = 0$$
$$W_p = W_2 = 4600 \quad A_p = A_2 = 132 \quad W_2A_2 = 607200$$
$$W_3 = 3800 \quad A_3 = 168 \quad W_3A_3 = 638400$$

$$\Sigma_1^n W = 12200 \qquad \Sigma_1^n W.A = 1245600$$
$$\Sigma_1^{p-1} W = 3800 \qquad \Sigma_1^{p-1} W.A = 0$$

From formula (E) the value of X_p is found to be about 15″, and it follows that the value of Y_p is about 81″. The position of these three loads is therefore a possible one, and from formula (F) the value of M_{fff} is found to be 496,300 inch-lbs.

There is also room on the span for one car, with the hind wheels of the car in front, and the front wheels of the car behind. Without going into details, the following results will be found, considering the M_{fff} under the hind wheels of the central car :—

$$\Sigma_1^n W = 16800$$
$$\Sigma_1^{p-1} W = 8400$$
$$\Sigma_1^n WA = 1684800$$
$$\Sigma_1^{p-1} WA = 136800$$

From these data, the value of X_p is found to be -2″, and therefore this is not a possible position.

Comparing the two values found for the M_{fff}, it will be seen that the latter, namely 496,300 inch-lbs., is the greater, and must therefore be used in a calculation for the strength of the road-bearers, after making the necessary allowance for roadway and so forth.

Formulæ of a somewhat similar nature were given by Professor T. Alexander.* These latter are somewhat more extensive in their range, but it will be found that the formulæ given here are easier to use for the limited amount of information required under the conditions of the present problem.

It has been stated that the scope of this paper is limited to the case of road-bearers of practically constant section, and that the value of the greatest M_f at different points is not material, but it is perhaps permissible to add that a determination of such a sequence of maximum bending moments, of an accuracy quite sufficient for all

* *Engineering*, January 10th, 1879.

practical purposes, could be obtained from the information given by the present formulæ. The magnitude of the M_{fff} would be obtained as usual, and its position would be determined by

$$X_p + A_p$$

If this position were not exactly at the centre of the span, it would be necessary to take a second position, symmetrically situated with regard to the span, as it is obvious that the series of loads could cross from either direction. The bending moment at all points between these two positions would be taken as equal to the maximum, and the value at any other point would be given by the following formula,

$$y = M_{fff}\left\{1 - \left(\frac{P-x}{P}\right)^2 + \frac{2x(P-x)}{P^2}(\alpha\lambda)^2\right\}$$

where x is the distance of the required point from the nearer support, y the value of the maximum M_f at that point, M_{fff} the value found from the previous formulæ, P the distance of the nearer position of M_{fff} from the support under consideration, α the ratio of the average distance between the various concentrated loads to the span, and λ the ratio of the heaviest load to the average load.*

It will be seen that the first two terms within the bracket give the usual parabola for a single, or for a continuous distributed, load, and that the third term is a correction to allow for the fact that the loads are concentrated.

The formulæ for determining the magnitude only of the M_{fff} have been employed to find the maximum bending moments produced on the road-bearers of bridges whose spans vary from 4′ to 30′, by those combinations of moving loads that might more commonly be met with on military bridges, and that are likely to have a predominating influence on the size of the road-bearers.†

In these calculations, the data as to the various loads and their distances apart, are sometimes taken from official publications, sometimes derived from actual measurements, and sometimes obtained from information kindly given by the officers commanding different units, and also through the courtesy of several firms. All wagons and so forth have been assumed to be loaded to their maximum capacity. In the case of all horse-drawn guns and vehicles, the average loads produced by horses of the stamp employed have also been taken into account, and it has moreover been assumed in every case that a gun or vehicle is followed as closely as possible by the horses of other vehicles. For the larger spans therefore, the values of the M_{fff} given are too high, if the vehicles cross one at a

* This approximate formula would not hold good for values of $(\alpha\lambda)$ greater than about ·6.

† The combinations calculated are given in Appendix II.

time only, more especially if the horses are taken out, and the vehicle passed over by hand.

The live loads produced by these various vehicles are converted to equivalent dead loads by multiplication by the factor 3/2, except in the case of the traction engines and lorries, where the factor is taken as 2, to allow for a possible want of balance of the moving parts.

For the sake of comparison, and also for completeness, the maximum bending moments produced over the same spans by loads usually considered as distributed, that is to say, infantry and cavalry in various formations, have also been shown, the loads being taken as continuous over the span, and of the usual values.

In all cases the additional bending moment produced by an appropriate roadway has also been calculated and added to the result shown.

The information obtained is not tabulated, but is given in a series of graphical charts, *Plates* II. and III.

THE GRAPHICAL REPRESENTATION OF FORMULÆ.

It is perhaps somewhat unnecessary to say anything about the value of graphical charts in general, as they are so universally employed in every branch of knowledge, but it still seems doubtful if they are sufficiently used for the representation of formulæ likely to be required on service. As a general rule, a graphical chart can only be considered an economy if the time needed for its preparation is less than the aggregate time that would be necessary for the separate calculations of individual cases that it is likely to replace. On service, however, a small saving of time in the field, even on one occasion only, is cheaply purchased by the labour, however considerable that may be, of preparing such charts in peace.

In certain cases, tabulated results may be equally useful, or even more so, for example see *Plate* XV.; but where interpolation may be necessary, the chart has a decided advantage.

Some other examples of charts, prepared by the author, are given in *Plates* IV. to XVII. These example by no means exhaust the formulæ for use in the field, that might conveniently be represented in this way, and many more might be drawn. With this idea in view, a few remarks about the methods of making them may not be out of place.

The subject of graphical charts in general is a most fascinating one, and many books and articles have been written on it. Among these may be mentioned *Traité de Nomographie*, by Maurice d'Ocagne, a work that is most exhaustive in its treatment; "The Construction of Graphical Charts," by John B. Peddle, being three articles that appeared in *The American Machinist*, May 30th, September 19th, and November 14th, 1908; and "The Use of a Logarithmic Scale in Plotting Curves," by R. S. Scholefield, *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CLIV., p. 287.

The simplest form of graphical chart consists of two comparative scales, examples of which can be seen on the horizontal axes of *Plate* XI. Sometimes several scales are carried on parallel lines, as in *Plate* IV., and also in the lower portions of *Plates* XII. and XIII.

The most common form of graphical representation is with two axes of co-ordinates at right angles, evenly divided. A single line, straight or curved, traced on this chart, will establish the relation between two variables, for instance, any of the lines on *Plate* X. By the use of a succession of these lines, the relations between three variables can be exhibited; as an example of this form of chart, see *Plate* IX.

Even in these simple forms of charts, any time spent in choosing the scales of the co-ordinates so that the requisite portion of the graphs may fit into the area of the paper available, is very well expended.

In certain cases, other methods of dividing the scales of co-ordinates may be useful. It may be required to get a large range of values along one or both of the axes, without unduly reducing the graduations of the lower values. For this purpose, one or both scales may be divided in proportion to the logarithms of the quantities represented, as for example *Plate* XI., for one axis so divided, and *Plate* XII., where both are treated in this way.

Again, it may be possible, by dividing an axis logarithmically or in proportion to the square or some other power of the variable, to change a graph that would be represented by a curve, into a straight line. This makes it easier to ensure accuracy in the preparation of the chart, and also saves much labour, it being only then necessary to determine two points on each graph, to be joined by a straight line, instead of having to find a number of values, and then pass a curve through the points so plotted.

The drawback to these methods is that it is not so easy to interpolate values by eye, but to anyone accustomed to using a slide-rule this difficulty would not be felt, and in any case the degree of accuracy obtained by an even division of the small graduations would be practically sufficient, if the intervals on the scale were not too large.

The available area of the paper may sometimes be utilized to better advantage by not having the axes at right angles. This is shown in *Plates* II. and III.

By superimposing two or more of these charts on each other, four or more variables may be dealt with. For an example of this, see *Plate* I.

It is sometimes convenient to use a form of polar co-ordinates ; for an example of this, refer to the paper by R. S. Scholefield, in the *Proceedings of the Civil Engineers.*

Another very useful form is what is known as an alignment chart. This consists in its simple shape of three parallel straight lines, suitably divided, the required value being read on one of the lines by holding a straight-edge through the corresponding points on the other two. By this means, three variables can be connected.* An instance of this simple form is *Plate* XIV.

These simple forms can be superimposed upon one another; *Plate* XVI. is an example where the outer lines are common, the two separate central scales representing two different relations between the variables. Again, *Plate* XVII. shows a series of charts, with a common central scale, and different pairs of outer scales to introduce a fourth variable.

It is also possible to deal with four or more variables on a single chart, composed, however, of more than three lines.

The disadvantage of this alignment method, is that the chart cannot be read by itself, but needs the application of a straight-edge or a piece of thread.

The actual charts given, as far as their employment is concerned, speak for themselves, but a few explanatory words may be useful about some of them.

Plates I. to III. have already been referred to in the text.

Plates V., VI. and VII. are calculated from Gordon's formula for columns, except that safe and not breaking loads are shown.

Plates VIII. and IX. are drawn on the assumption that the spars are frustra of cones.

Plate X. is perhaps of little practical importance, but is interesting as a graphical solution of a somewhat complicated problem.

Plates XII. and XIII. are noteworthy as embodying the results of recent experiments at Chatham as to man-power applied to tackle falls and to capstan bars. The results on falls, up to a maximum of 60 men, appeared to give a straight-line law, with an average of about 80 lbs., or $\frac{3}{4}$ cwt., per man. The results on the capstan bars were rather less than those given in *Military Engineering*, Part III., para. 71.

Plate XIV. is inspired by the figures published by Capt. E. N. Stockley, R.E.†

Plate XV. gives tabulated results for the British Standard Sections

* The principle of this chart is given very briefly in Appendix III.
† *R.E. Journal*, October, 1907.

of Rails. The dimensions are taken from the publications of the Engineering Standards Committee, and the values for the section moduli, and so forth, have been worked out by the graphical method described elsewhere by the author.* *Plate* XVI. is prepared from these values.

Plate XVII. is based on the usual formula for demolitions contained in *Military Engineering*, Part IV., and contains in addition a formula devised by the present Chief Instructor in Fortification, for the hasty calculation of the charge necessary to demolish built-up girder bridges, crrying standard lines of railway.

* *The Engineer*, July 15th, 1910.

APPENDIX I.

M_{fff} DUE TO *n* LOADS ON A SUPPORTED BEAM.

Let the loads be situated as in *Fig.* 2 of the text. The reaction at the left-hand support is,

$$Q = W_1\frac{L-x-A_1}{L} + W_2\frac{L-x-A_2}{L} + \ldots + W_p\frac{L-x-A_p}{L} + \ldots + W_n\frac{L-x-A_n}{L}$$

$$= \Sigma_1^n W - \Sigma_1^n W\frac{x}{L} - \frac{1}{L}\Sigma_1^n WA$$

The M_f under W_p is,

$$Q\,(x+A_p) - W_1(A_p - A_1) - W_2(A_p - A_2) - \ldots - W_{p-1}(A_p - A_{p-1})$$

This may be written,

$$\left\{\Sigma_1^n W - \Sigma_1^n W\frac{x}{L} - \frac{1}{L}\Sigma_1^n WA\right\}(x+A_p) + \Sigma_1^{p-1}WA - A_p\Sigma_1^{p-1}W$$

To find when M_f is a maximum, differentiate with respect to x, whence,

$$X_p = \tfrac{1}{2}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} - A_p\right\}$$

Substitute this value in the expression for M_f under W_p, and simplify. Then the M_{fff} under W_p is,

$$\frac{\Sigma_1^n W}{4L}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} + A_p\right\}^2 + \Sigma_1^{p-1}WA - A_p\Sigma_1^{p-1}W$$

APPENDIX II.

SCHEDULE OF LOADS CALCULATED

A. Staff and Headquarters.

Typical heavy touring motor cars.
Printing wagon.

B. Troops.

Infantry in fours.
do. file.
do. single file.
Cavalry in half-sections.
do. single file.

C. Vehicles Common to All Arms.

G.S. wagon (ordinary horses).
G.S. limbered wagon.
Carts (water, cable, S.A.A.).

D. Artillery Vehicles.

13-pr. Q.F. gun carriage with limber.
Ammunition wagon with limber.
18-pr. Q.F. gun carriage with limber.
Ammunition wagon with limber.
5″ B.L. howitzer carriage with limber.
Ammunition wagon with limber.
60-pr. B.L. gun carriage with limber.
Ammunition wagon with limber.
4·7″ B.L. gun carriage with limber.
6″ B.L. howitzer carriage with limber.
G.S. wagon (heavy horses).
Light tractor with 60-pr. gun, 4·7″ gun, or 6″ howitzer.

E. Engineer Vehicles.

Double tool cart.
Pontoon or trestle wagon.
Cable wagon.
Special wagon for wireless telegraph company.
Air-line wagon, 6-horsed.
Gas reservoir wagon.

F. Transport Vehicles.

Heavy traction engine and trucks.
Light traction engine and trucks.
Service type of lorry.
Heavy commercial lorry.
Bread and meat wagon.
Ambulance wagon.
Heavy hired transport—Farm wains.
Large delivery vans.

APPENDIX III.

ALIGNMENT CHARTS.

It can be proved very easily that if corresponding values, x', y'; x'', y''; etc., of two variables x and y, connected by the relation,

$$ax + by = c$$

are plotted along parallel straight lines AA′ and BB′, from any base line AB, then the straight lines joining these respective values will all pass through a point C′, as in *Fig.* 4.

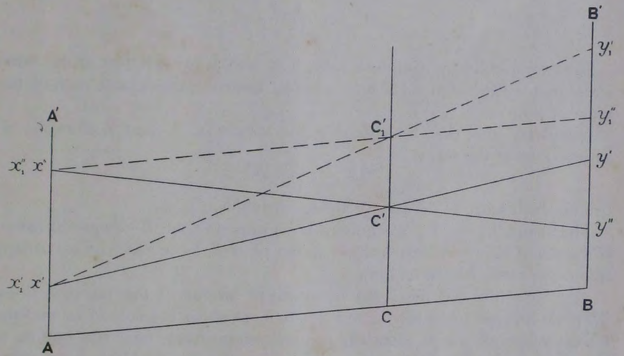


FIG. 4.

If CC′ be drawn parallel to AA′, then it can be shown that

$$AC : BC :: b : a \quad \ldots\ldots (1)$$

and that

$$CC' = \frac{c}{a+b} \quad \ldots\ldots (2)$$

If c be changed to c_1, then these intersections take place at a new point C'_1. As the proportion (1) is independent of c, it follows that this new point C'_1 will be on CC′.

Thus a third variable z can be plotted along CC′, the relation being

$$ax + by = (a + b) z$$

The alignment form of chart is generally employed most usefully by plotting the logarithms of the variables.

Thus if the relation is

$$X . Y = Z$$

Then $$\log X + \log Y = \log Z$$

which may be written $$\frac{x}{L_1} + \frac{y}{L_2} = \frac{z}{L_3}$$

where $$x = L_1 \log X$$

L_1 being the modulus or coefficient by which log X is multiplied to get the plotted length x, and so forth.

From what has gone before, it will be seen that z is plotted on an intermediate line, dividing the distance between the lines on which x and y are plotted respectively in the ratio

$$L_1 : L_2$$

and also that the scale at which z must be plotted is given by

$$L_3 = \frac{L_1 L_2}{L_1 + L_2}$$

For example, in the simplest case, if x and y are plotted at the same scale, then z is plotted on a line midway between them, and at half the scale of x or y.

It will be seen that by choosing the values X, Y and Z suitably, all expressions of the form

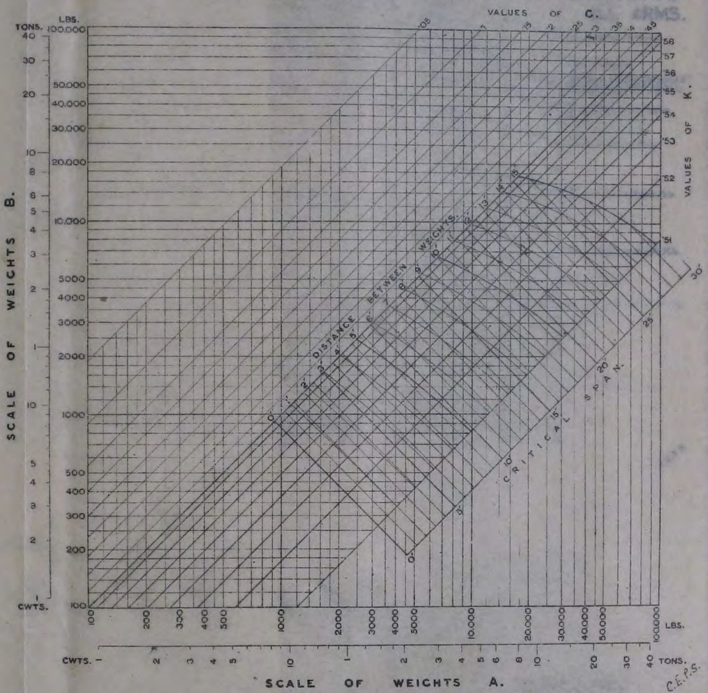
$$U^p . V^r = n . W^s$$

can be dealt with, U, V and W being variables.

The scales L_1 and L_2 are generally chosen, so that the required range of values of X and Y respectively, when plotted as x and y, may occupy about the same length of line.

The base line AB need not be at right angles to the parallel lines. Though it is not generally shown at all, its position is selected so that the lowest values of x and y occupy convenient positions near the bottom of the chart. The graduation of z can be located by calculating one value arithmetically, and finding this point by the use of a straight-edge.

CRITICAL SPAN
FOR
MAXIMUM BENDING MOMENT
PRODUCED BY A
PAIR OF MOVING WEIGHTS ON A SUPPORTED BEAM.



The M_{mx} always occurs under the Heavier Weight.

For spans less than the critical span, when it is at the centre of the span.

For spans greater than the critical span, when it, and the centre of gravity of the two weights, are at equal distances from the respective supports.

Enter the Chart by Scale A for the Heavier Weight and Scale B for the other weight.

From the intersection, run the eye parallel to the diagonal lines giving the value of K, until the curved line, representing the distance between the weights, is met.

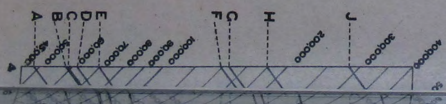
From this point, carry the eye along the transverse diagonal lines to the scale of critical spans.

If the span in question is greater than the critical span, the position of the centre of gravity can be found by entering the Chart by Scale B for the Heavier Weight, and Scale A for the other weight.

The intersection gives the value of G, the distance of the centre of gravity from the Heavier Weight, expressed as a fraction of the distance between the weights.

N.B.—$R = \dfrac{\text{Heavier Weight}}{\text{Other Weight}}$ $\qquad$ $K = \dfrac{\text{Distance between Weights}}{\text{Critical Span}}$

$$K = 1 + R - \sqrt{R^2 + R}.$$


A
B
C
D
E
45,000
50,000
60,000
70,000
80,000
90,000
100000
F
G
H
200,000
J
300,000
400,000
4

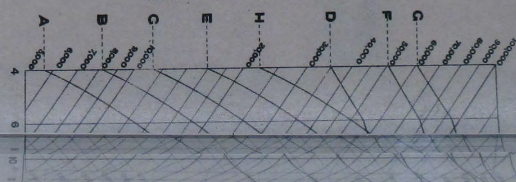
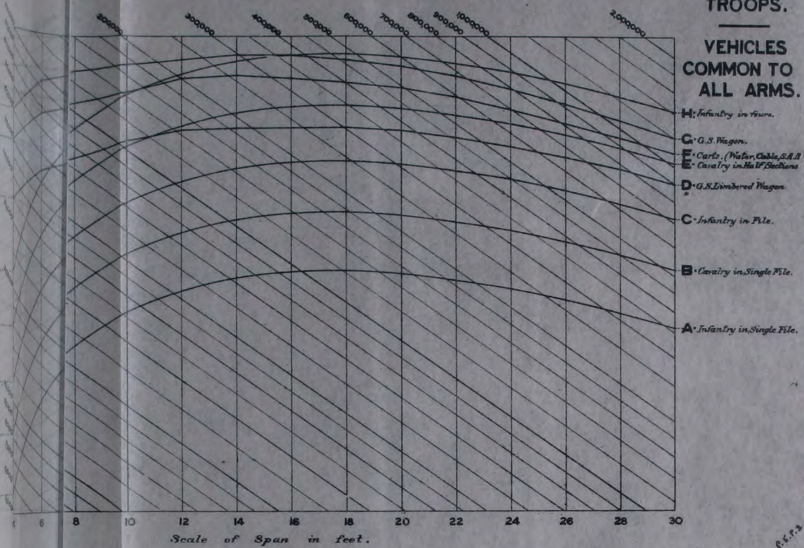

Scale of Mfff in inch-lbs.
A
B
C
E
H
D
F
G
5,000
6,000
7,000
8,000
9,000
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100000
4
6

PLATE II.

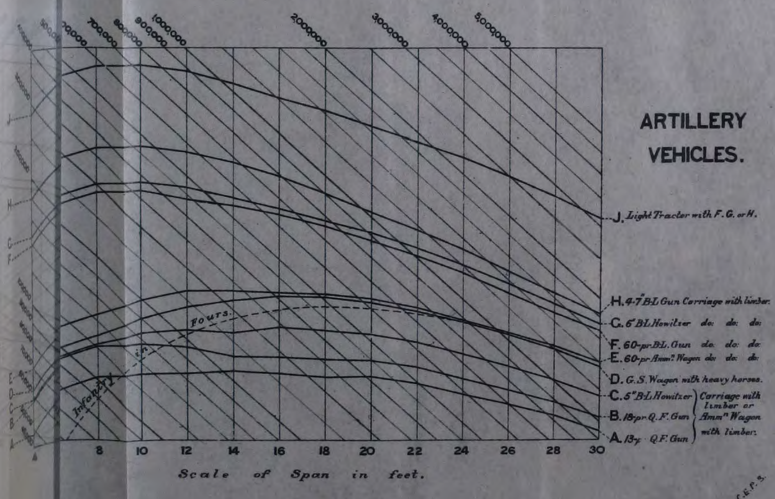
TROOPS.

VEHICLES COMMON TO ALL ARMS.



Scale of Mfff in inch-lbs.

ARTILLERY VEHICLES.



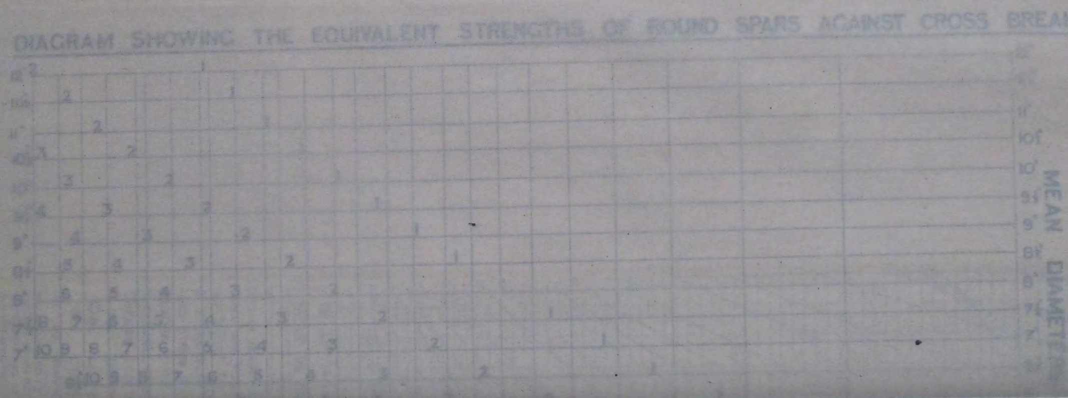


DIAGRAM SHOWING THE EQUIVALENT STRENGTHS OF ROUND SPARS AGAINST CROSS BREAKING.
MEAN DIAMETERS

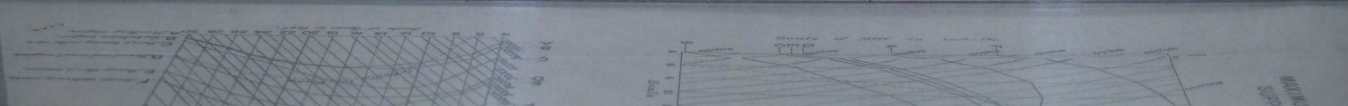
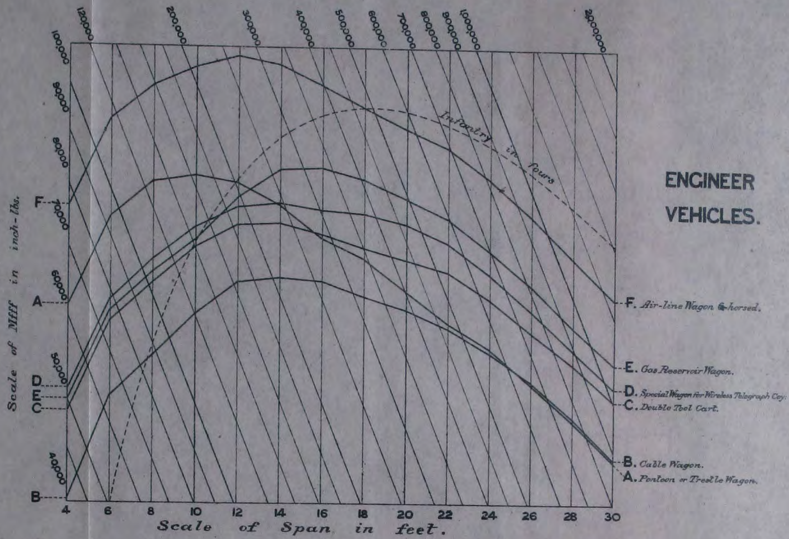


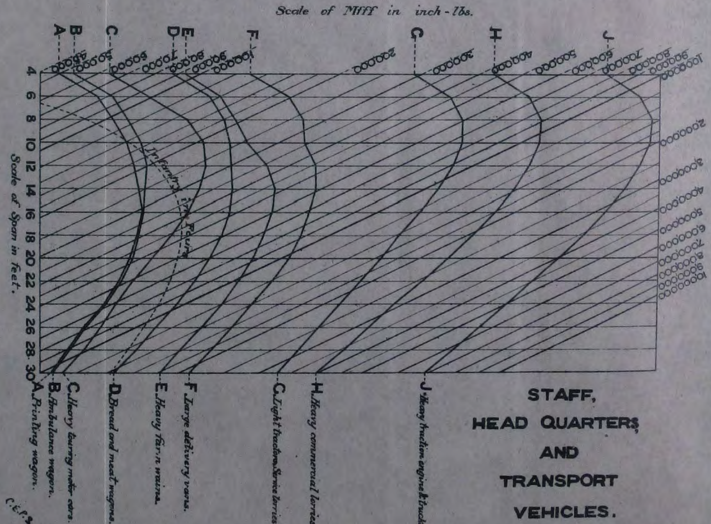
PLATE III.

MAXIMUM BENDING MOMENT ON SUPPORTED ROAD BEARERS.

ENGINEER VEHICLES.

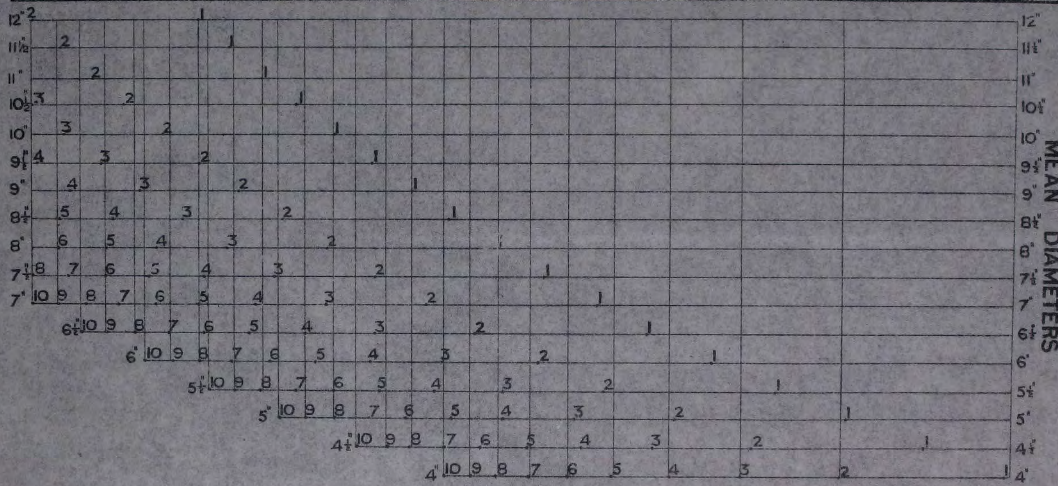


STAFF, HEAD QUARTERS AND TRANSPORT VEHICLES.



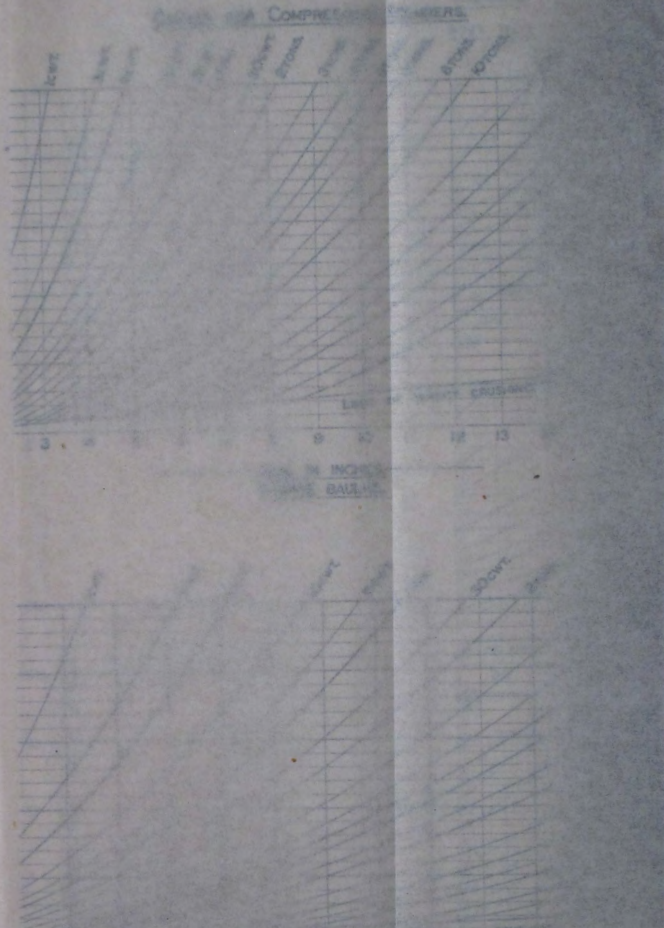
C.E.P.

DIAGRAM SHOWING THE EQUIVALENT STRENGTHS OF ROUND SPARS AGAINST CROSS BREAKING.



IN THE ABOVE DIAGRAM THE VERTICAL LINES DETERMINE THE EQUIVALENT NUMBER OF DIFFERENT SIZED SPARS OF THE SAME TOTAL STRENGTH.

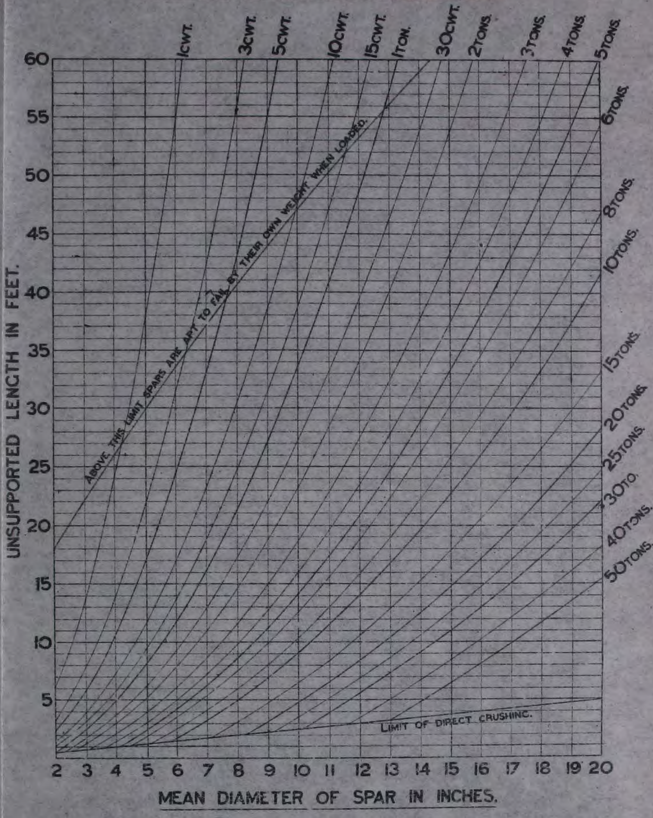
PLATE IV.


COMPRESSION MEMBERS.
LINE OF DIRECT CRUSHING
LINE OF DIRECT CRUSHING


UNSUPPORTED LENGTH IN FEET.

PLATE V.

Curves for Compression Members.



This Plate gives the safe Compressions in round Baltic Fir spars. It has been calculated for cases where the ends are 'round' or where the fixing is not sufficiently good to consider them 'fixed'. The probable eccentricity of loading, due to lashings etc. and the effects of live loads, have been allowed for by keeping the safe crushing stress as low as 1000 lbs pr: sq: inch.

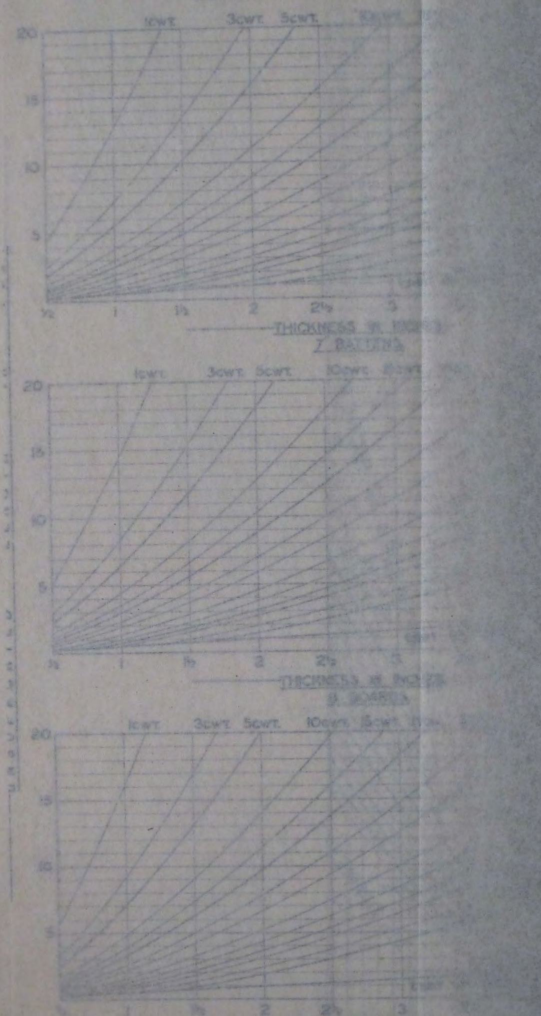
In the case of derricks etc the compressions in the various members, due to a weight W, are as follows, under the most unfavourable circumstances, in actual practice,

Single derrick		1·5W	Sheers,	leg with leading block	·9W
Swinging derrick,	standing spar	1·7W	do:	other leg	·7W
do:	swinging arm	1·0W	Gyn.	leg with leading block	·6W
do:	back strut	·3W	do:	other legs	·4W

These curves are not applicable to spars that are transversely loaded in addition.

Example—To find size of sheer legs 35 feet long to crutch, to lift a weight of 2 tons. Compression in leg with leading block is ·9×2 tons = 1·8 tons. Following down between the curves representing 30cwt. & 2 tons, it is seen that the horizontal line representing an unsupported length of 35 feet is met at a point that indicates the use of a spar nearly 12 ins: mean diameter. Compression in the other leg is ·7×2 tons = 1·4 tons and in a similar manner the mean diameter of this leg is found to be 11 ins:

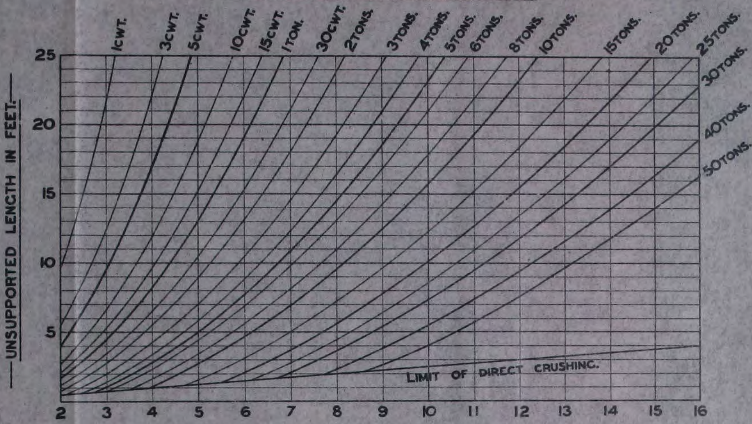
Curves for Compression Members



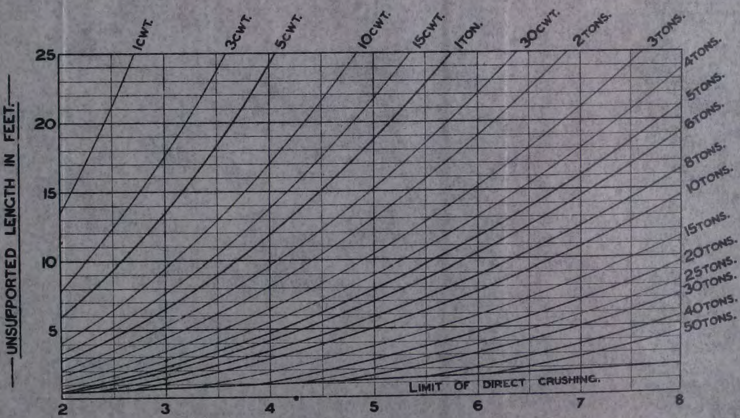
This plate gives the safe compressions in Baltic Fir ... considered "fixed" and the loading symmetrical. Safe ... square inch. The curves are not applicable to planks ...

PLATE VI.

CURVES FOR COMPRESSION MEMBERS.



SQUARE BAULKS.



RECTANGULAR BAULKS SIDES 2:1.

THIS PLATE GIVES THE SAFE COMPRESSIONS IN BALTIC FIR BAULKS. THE ENDS HAVE BEEN CONSIDERED "ROUND" & THE LOADING SYMMETRICAL. SAFE CRUSHING STRESS TAKEN AS 1500LBS. PER SQUARE INCH. THE CURVES ARE NOT APPLICABLE TO BAULKS TRANSVERSELY LOADED IN ADDITION.

WEIGHT OF ROUND SPARS OF BALTIC FIR.

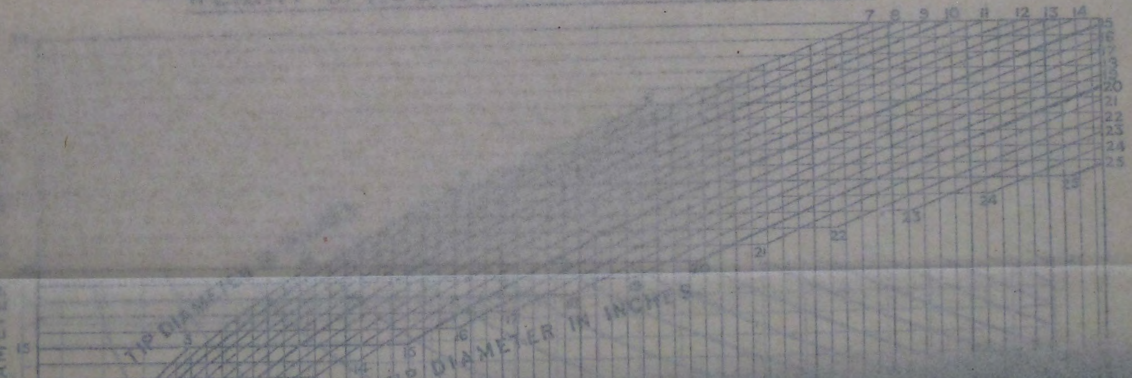
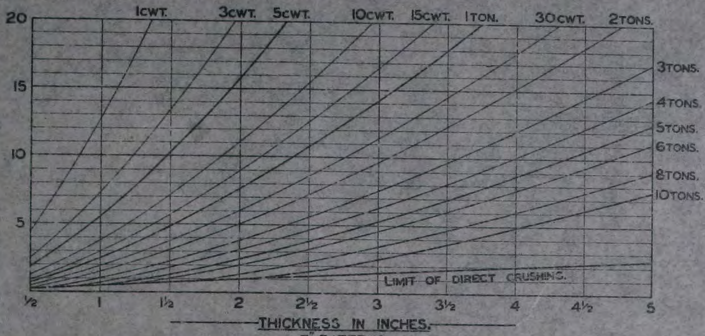


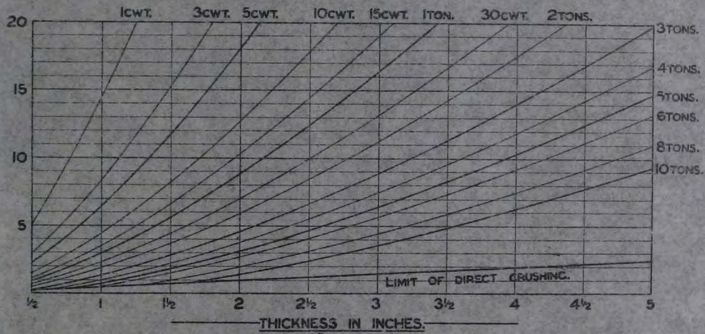
PLATE VII.

CURVES FOR COMPRESSION MEMBERS.

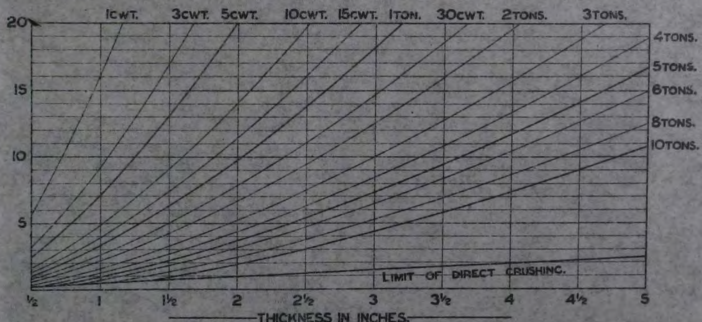
UNSUPPORTED LENGTH IN FEET



7" BATTENS.



9" BOARDS.

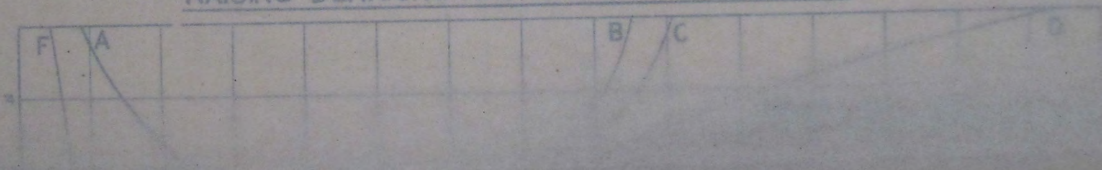


11" PLANKS.

THIS PLATE GIVES THE SAFE COMPRESSIONS IN BALTIC FIR PLANKS ETC. THE ENDS HAVE BEEN CONSIDERED "FIXED" AND THE LOADING SYMMETRICAL. SAFE CRUSHING STRESS TAKEN AS 1500LBS. PER SQUARE INCH. THE CURVES ARE NOT APPLICABLE TO PLANKS TRANSVERSELY LOADED IN ADDITION.

C.E.P.S.

RAISING DERRICKS AND SHEERS BY LEVERS.



CENTRE OF GRAVITY OF ROUND SPARS.

CENTRE OF GRAVITY OF ROUND SPARS.

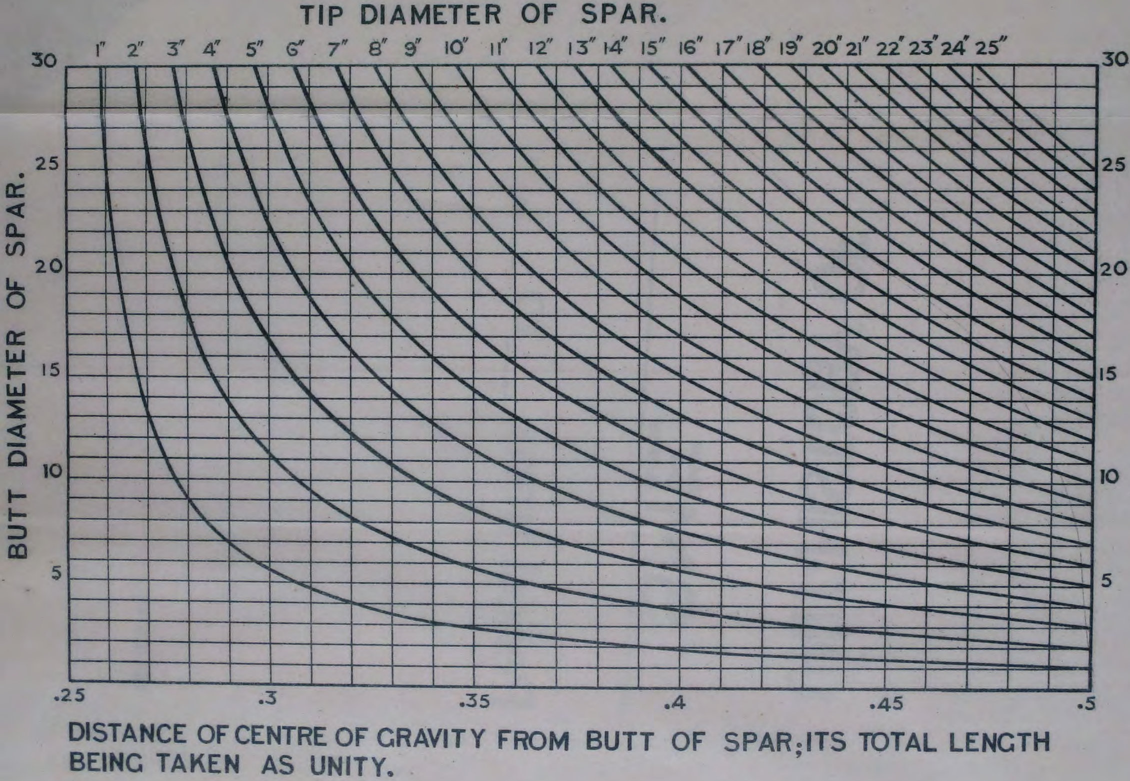
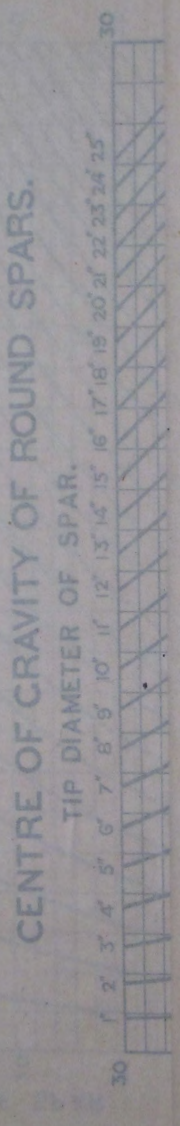
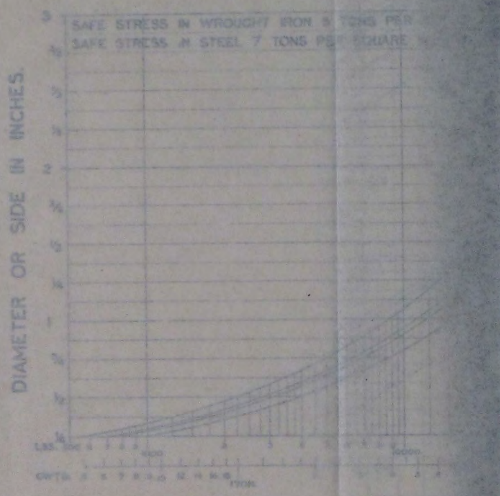


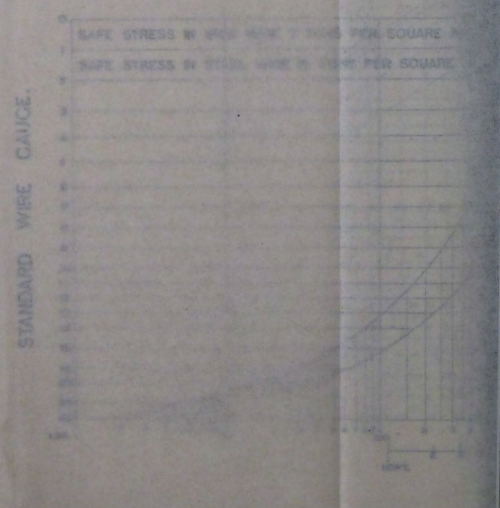
PLATE IX.



SAFE STRESS IN WROUGHT IRON
OF ROUND AND SQUARE



SAFE STRESS IN IRON AND ST



RAISING DERRICKS AND SHEERS BY LEVERS.

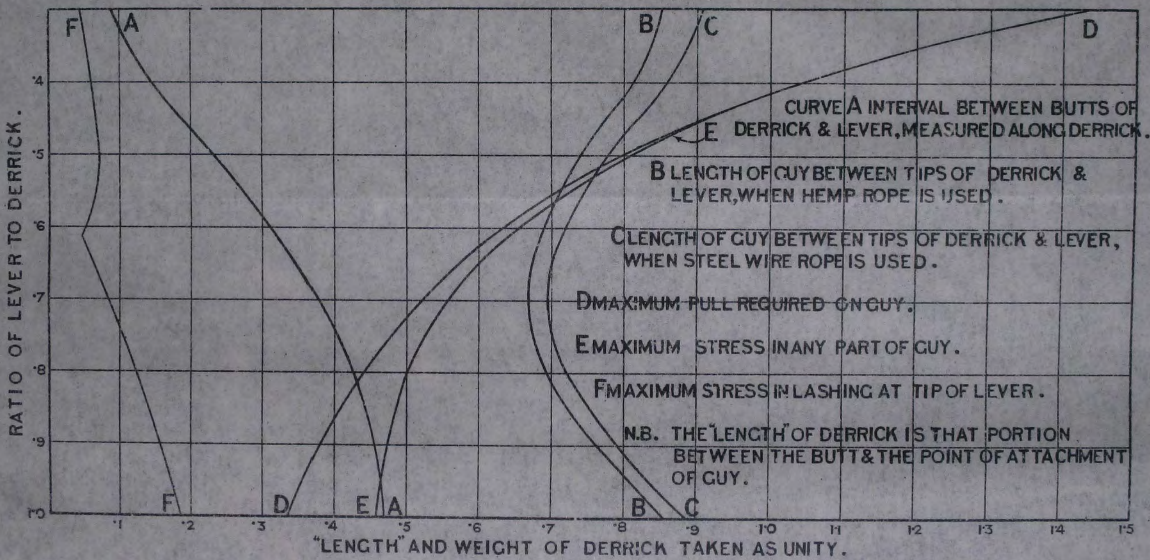
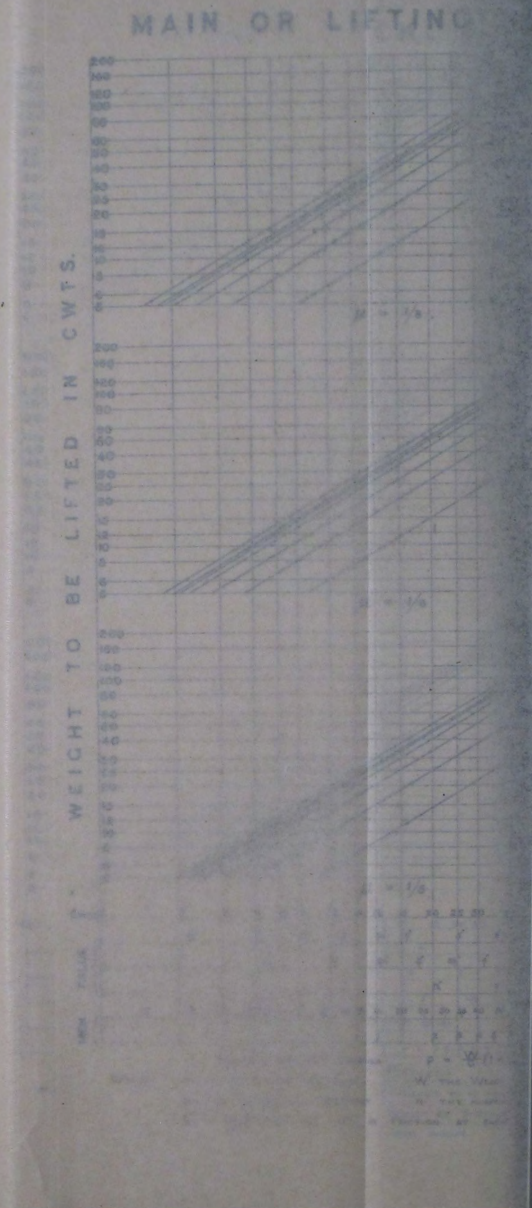
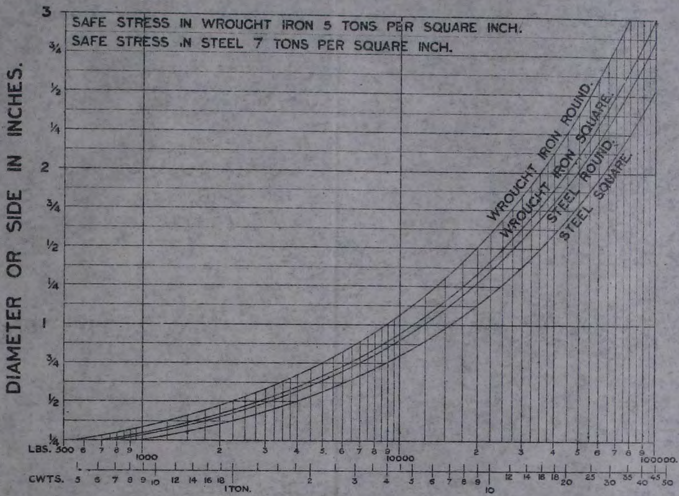


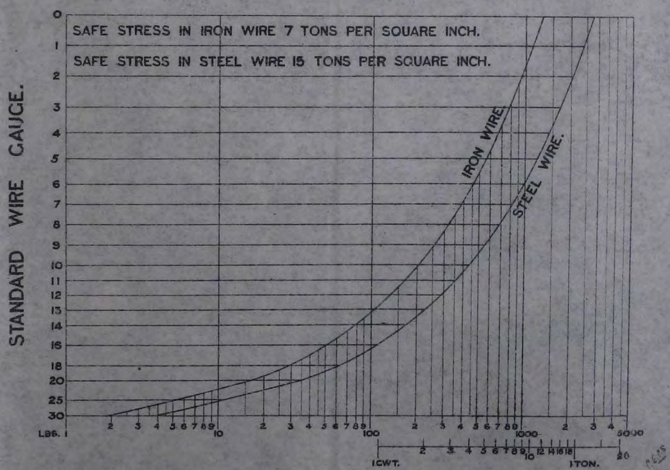
PLATE X.

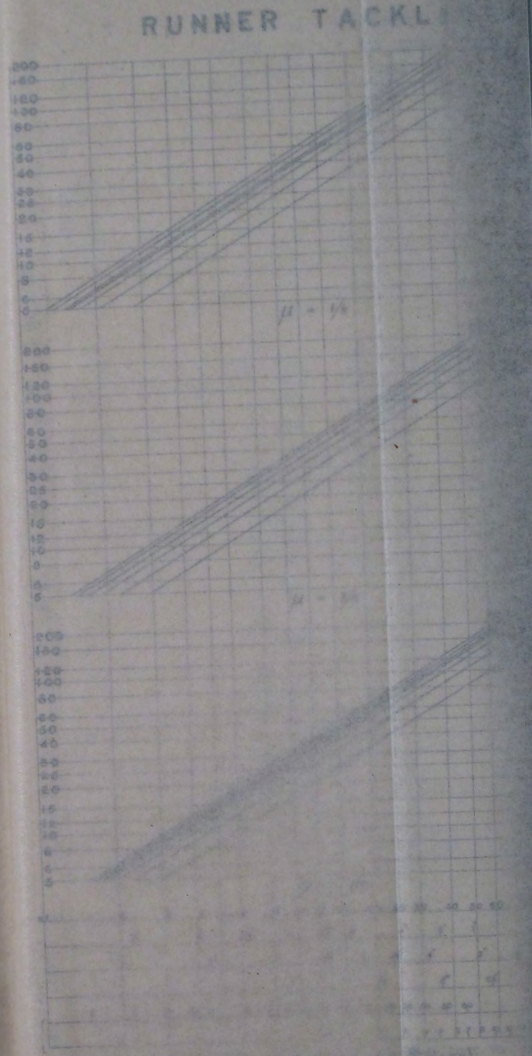

MAIN OR LIFTING
WEIGHT TO BE LIFTED IN CWTS.

SAFE STRESS IN WROUGHT IRON AND STEEL BARS
OF ROUND AND SQUARE SECTION.

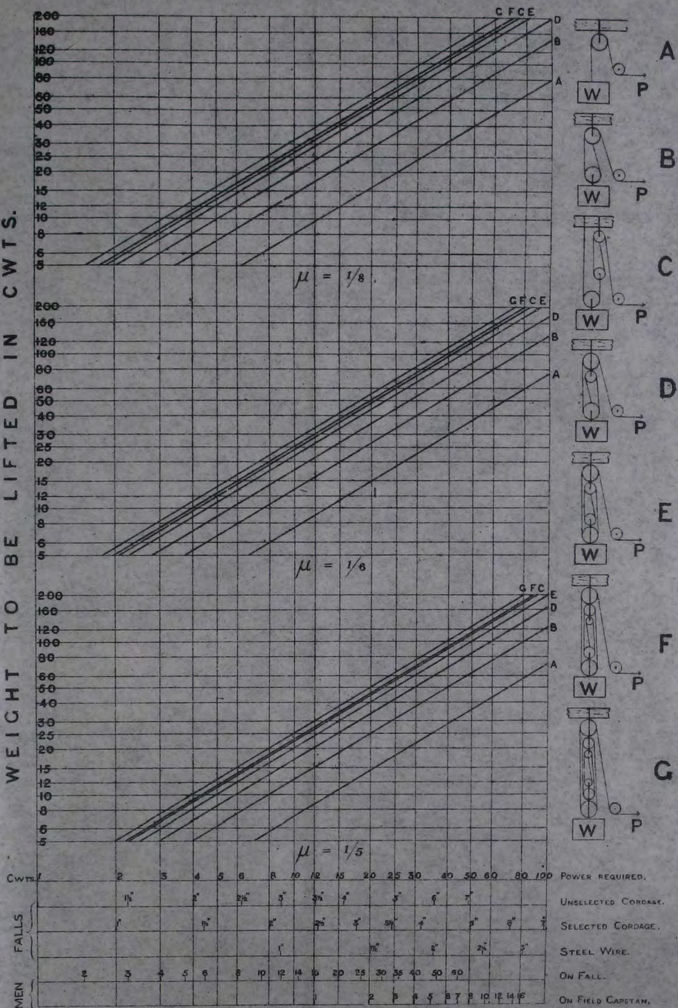


SAFE STRESS IN IRON AND STEEL WIRE.




RUNNER TACKL

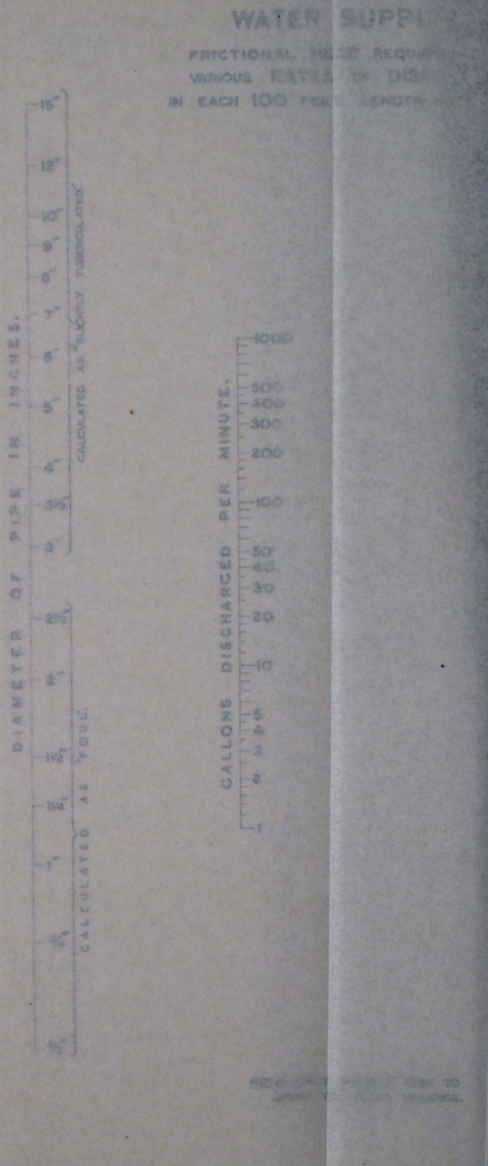
MAIN OR LIFTING TACKLES



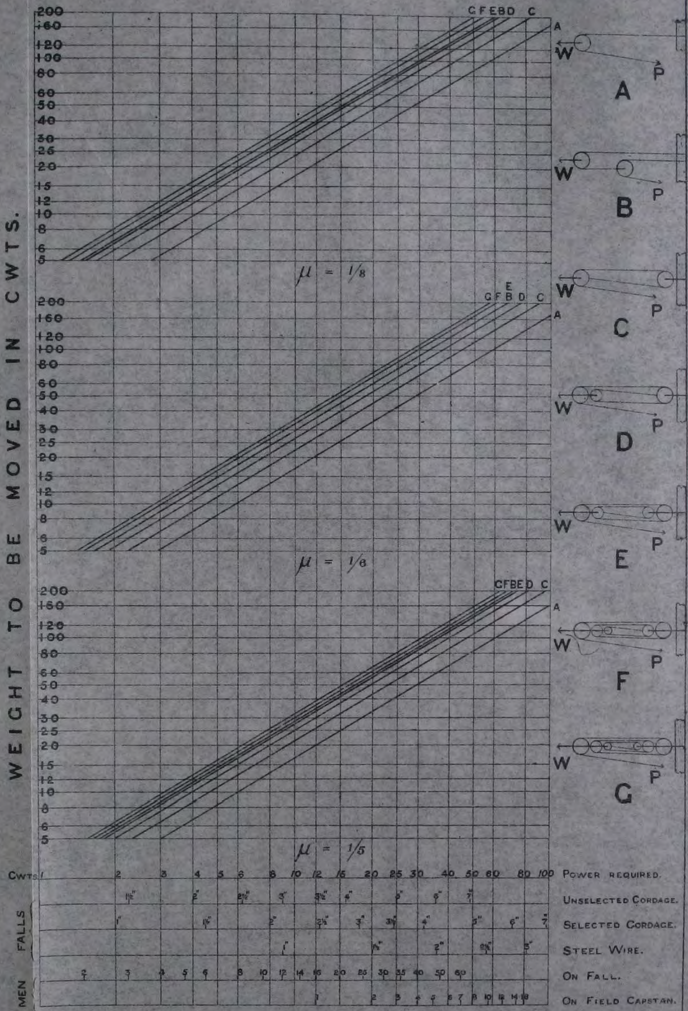
DERIVED FROM THE FORMULA $P = \frac{W}{G}(1 + \mu n)$

WHERE P IS THE POWER REQUIRED. W THE WEIGHT TO BE LIFTED.
G THE THEORETICAL ADVANTAGE n THE NUMBER OF SHEAVES.
μ A COEFFICIENT FOR LOSS BY FRICTION AT EACH SHEAVE.

C.E.P.S.


WATER SUPPL
FRICTIONAL HEAD REQUI
VARIOUS RATES OF DIS
IN EACH 100 FEET LENGTH
DIAMETER OF PIPE IN INCHES.
CALCULATED AS "FOUL."
CALCULATED AS "SLIGHTLY TUBERCULATED"
GALLONS DISCHARGED PER MINUTE.
1000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1

RUNNER TACKLES



DERIVED FROM THE FORMULA $P = \frac{W}{G}(1+\mu n)$

WHERE P IS THE POWER REQUIRED. W THE WEIGHT TO BE MOVED.
G THE THEORETICAL ADVANTAGE. n THE NUMBER OF SHEAVES.
μ A COEFFICIENT FOR LOSS BY FRICTION AT EACH SHEAVE.

C.E.P.S.

WEIGHT TO BE MOVED IN CWTS.

BRITISH STANDARD

BULL HE[illegible]

APPROXIMA[illegible]

I

I/y

WEIGHT PER YD W	60	65	70
HEIGHT h	[illegible]	[illegible]	5
UPPER FLANGE B	[illegible]	[illegible]	[illegible]
LOWER FLANGE b	[illegible]	[illegible]	[illegible]
AREA A	5.889	6.338	[illegible]
I	16.30	18.87	[illegible]
y	2.53	2.68	[illegible]
I/y	6.47	7.22	[illegible]

FLAT B[illegible]

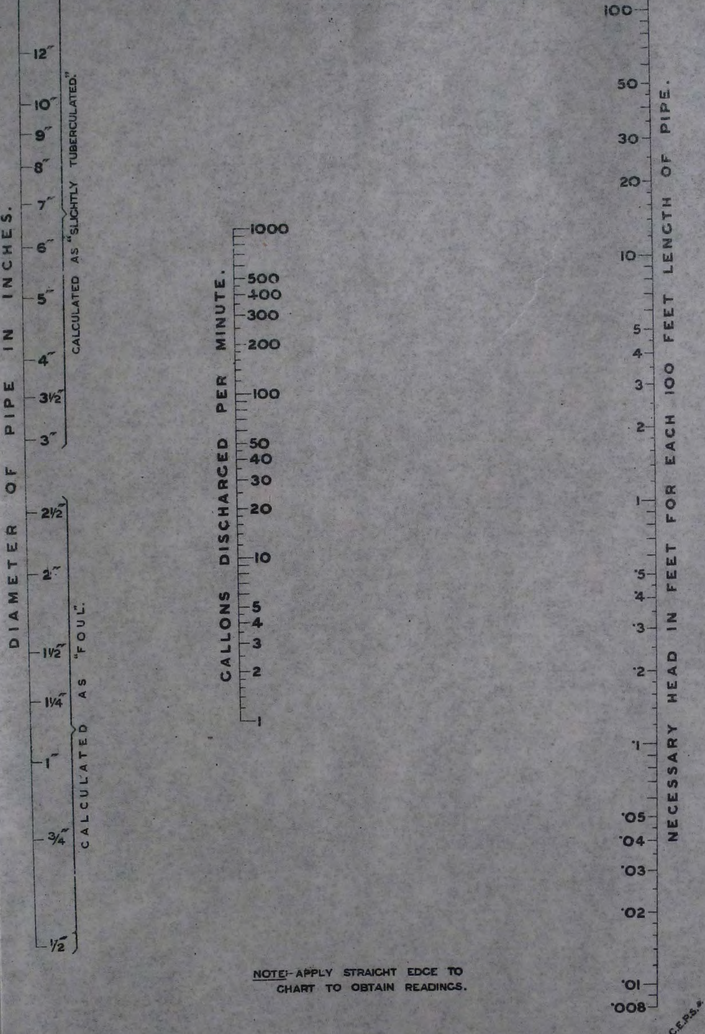
WEIGHT PER YD W	20	25
HEIGHT h	[illegible]	[illegible]
UPPER FLANGE B	[illegible]	[illegible]
LOWER FLANGE b	[illegible]	[illegible]
AREA A	1.959	[illegible]
I	1.73	[illegible]
y	1.26	[illegible]
I/y	1.37	[illegible]

WEIGHT PER YD W	65
HEIGHT h	[illegible]
UPPER FLANGE B	[illegible]
LOWER FLANGE b	[illegible]
AREA A	[illegible]
I	17.94
y	2.26
I/y	7.93

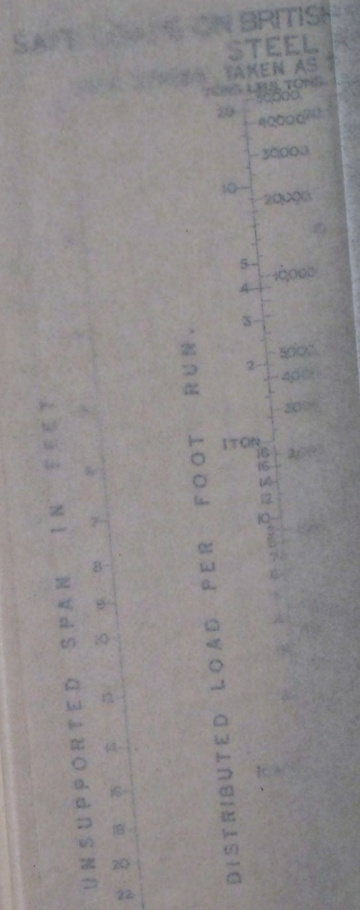
WEIGHT PER YD
HEIGHT
UPPER FLANGE
LOWER FLANGE
AREA
I
y

WATER SUPPLY.

FRICTIONAL HEAD REQUIRED FOR VARIOUS RATES OF DISCHARGE IN EACH 100 FEET LENGTH OF PIPE.

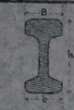


NOTE:- APPLY STRAIGHT EDGE TO CHART TO OBTAIN READINGS.


STEEL
TAKEN AS
UNSUPPORTED SPAN IN FEET
DISTRIBUTED LOAD PER FOOT RUN.

BRITISH STANDARD SECTION RAILS.

BULL HEADED RAILS.



APPROXIMATE VALUES.

$I = \cdot 0118\ Wh^2$

$y = \cdot 530\ h$

$I/y = \cdot 0222\ Wh$

WEIGHT PER YD. W	60	65	70	75	80	85	90	95	100
HEIGHT. h	4 3/4	4 7/8	5	5 1/8	5 3/8	5 15/32	5 35/64	5 23/32	5 28/32
UPPER FLANGE. B	2 5/16	2 3/8	2 7/16	2 1/2	2 9/16	2 11/16	2 3/4	2 3/4	2 3/4
LOWER FLANGE. b	2 5/16	2 3/8	2 7/16	2 1/2	2 9/16	2 11/16	2 3/4	2 3/4	2 3/4
AREA. A	5·869	6·338	6·883	7·318	7·802	8·331	8·811	9·284	9·800
I.	16·39	18·67	20·99	23·22	27·43	30·18	32·14	35·69	39·47
y.	2·53	2·58	2·65	2·72	2·84	2·89	2·92	3·03	3·16
I/y.	6·47	7·22	7·92	8·53	9·64	10·44	11·00	11·77	12·47

FLAT BOTTOM RAILS.

APPROXIMATE VALUES.

$I = \cdot 0133\ Wh^2$

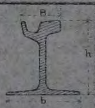
$y = \cdot 507\ h$

$I/y = \cdot 0263\ Wh$

WEIGHT PER YD. W	20	25	30	35	40	45	50	55	60
HEIGHT. h	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	3 15/16	4 1/8	4 5/16
UPPER FLANGE. B	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	1 31/32	2 1/16	2 5/32	2 1/4
LOWER FLANGE. b	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	3 15/16	4 1/8	4 5/16
AREA. A	1·959	2·449	2·943	3·438	3·925	4·427	4·902	5·376	5·900
I.	1·73	2·55	3·62	4·96	6·54	8·26	10·21	12·28	14·74
y.	1·26	1·38	1·50	1·63	1·76	1·87	1·98	2·07	2·17
I/y.	1·37	1·85	2·41	3·04	3·72	4·42	5·17	5·93	6·80

WEIGHT PER YD. W	65	70	75	80	85	90	95	100	
HEIGHT. h	4 7/16	4 5/8	4 13/16	5	5 3/16	5 3/8	5 9/16	5 3/4	
UPPER FLANGE. B	2 5/16	2 3/8	2 7/16	2 1/2	2 9/16	2 5/8	2 11/16	2 3/4	
LOWER FLANGE. b	4 7/16	4 5/8	4 13/16	5	5 3/16	5 3/8	5 9/16	5 3/4	
AREA. A	6·367	6·849	7·341	7·847	8·330	8·826	9·302	9·810	
I.	17·04	19·74	22·91	26·54	30·38	34·62	39·27	44·42	
y.	2·26	2·36	2·47	2·59	2·67	2·77	2·86	2·95	
I/y.	7·53	8·35	9·26	10·26	11·36	12·51	13·73	15·05	

TRAM RAILS.



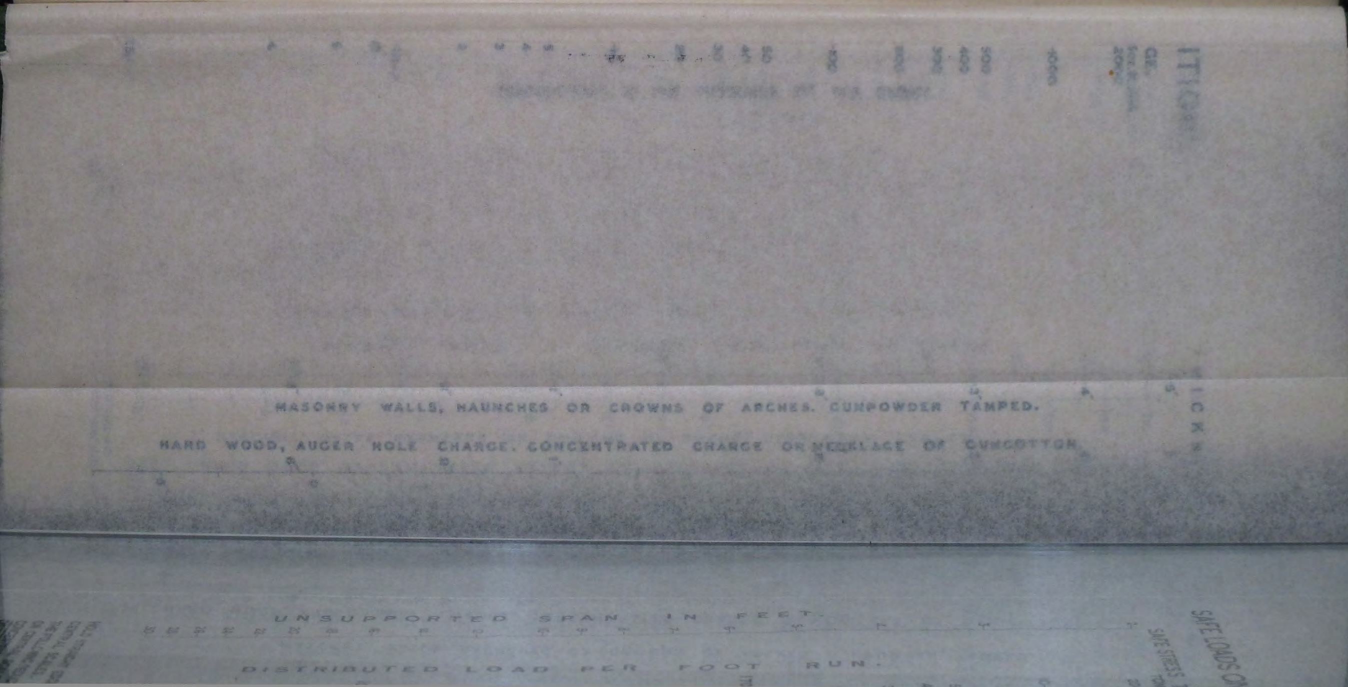
APPROXIMATE VALUES.

$I = 0125\ Wh^2$

$y = 531\ h$

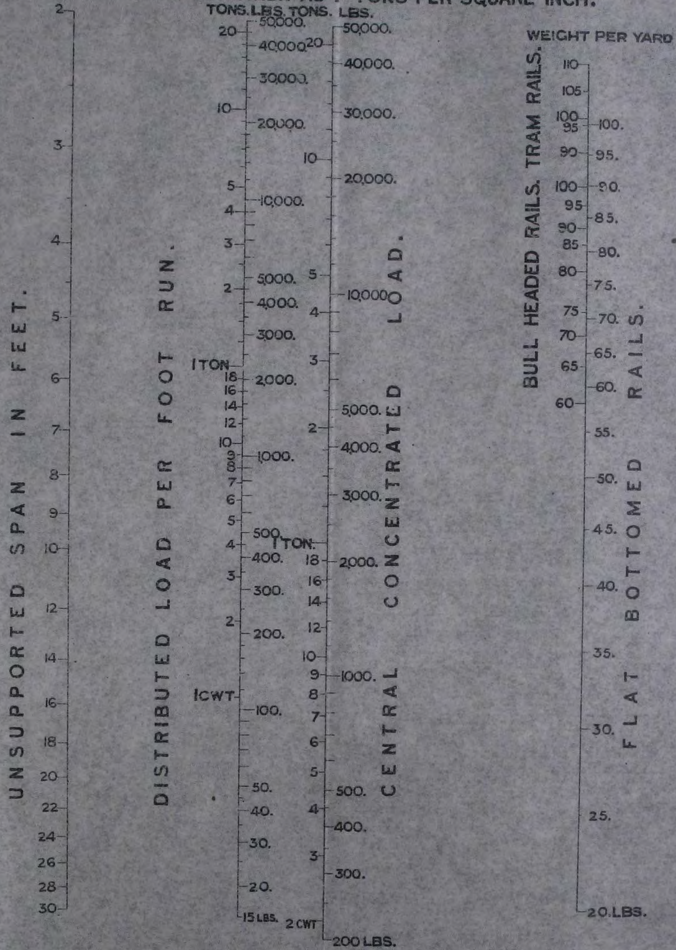
$I/y = 0235\ Wh$

WEIGHT PER YARD. W	90	95	100	105	110
HEIGHT. h	6 1/2	6 1/2	6 1/2	7	7
UPPER FLANGE. B	3 1/2	3 9/16	3 11/16	3 13/16	3 31/32
LOWER FLANGE. b	6 1/2	7	7	7	7
AREA. A	8·862	9·237	9·844	10·379	10·925
I.	47·41	50·79	52·45	63·43	67·75
y.	3·43	3·38	3·42	3·81	3·75
I/y.	13·83	15·02	15·34	16·64	18·07


MASONRY WALLS, HAUNCHES OR CROWNS OF ARCHES. GUNPOWDER TAMPED.
HARD WOOD, AUGER HOLE CHARGE. CONCENTRATED CHARGE OR NECKLACE OF GUNCOTTON.
UNSUPPORTED SPAN IN FEET.
DISTRIBUTED LOAD PER FOOT RUN.

SAFE LOADS ON BRITISH STANDARD SECTION STEEL RAILS.

SAFE STRESS TAKEN AS 7 TONS PER SQUARE INCH.



HOLD STRAIGHT EDGE ACROSS OUTER SCALES. READ RESULT ON CENTRAL SCALES.

THE FOLLOWING DEDUCTIONS MUST BE MADE FROM THE AMOUNTS READ ON CENTRAL SCALES:-

CONCENTRATED LOAD:- HALF THE TOTAL WEIGHT OF THE RAIL.

DISTRIBUTED LOAD:- THE WEIGHT, PER FOOT RUN OF THE RAIL.

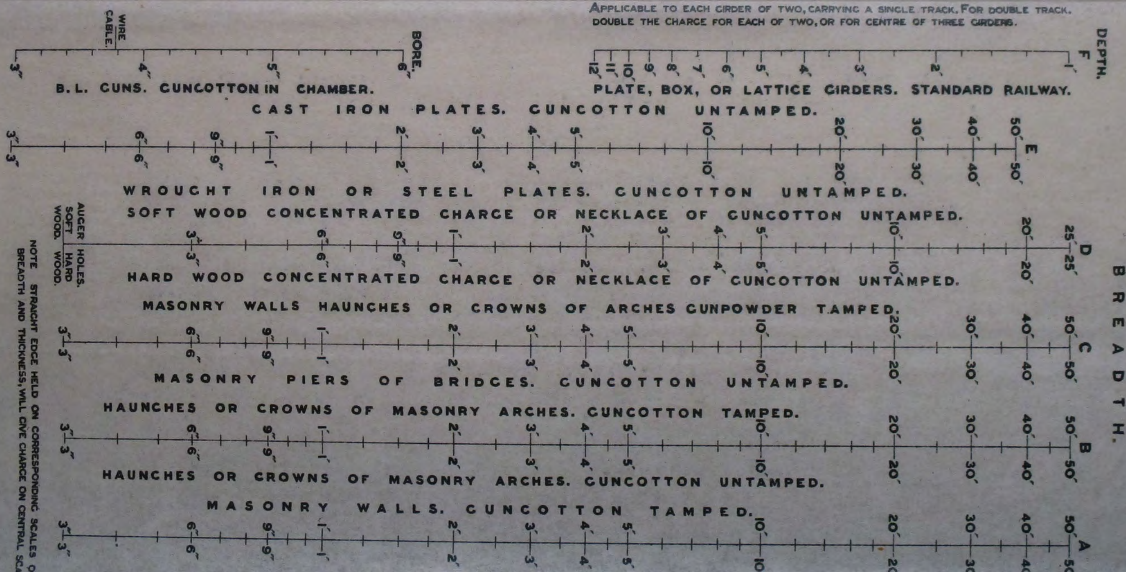

APPLICABLE TO EACH GIRDER OF TWO, CARRYING A SINGLE TRACK. FOR DOUBLE TRACK. DOUBLE THE CHARGE FOR EACH OF TWO, OR FOR CENTRE OF THREE GIRDERS.
DEPTH.
F
WIRE CABLE.
BORE.
B. L. GUNS. GUNCOTTON IN CHAMBER.
PLATE, BOX, OR LATTICE GIRDERS. STANDARD RAILWAY.
CAST IRON PLATES. GUNCOTTON UNTAMPED.
E
WROUGHT IRON OR STEEL PLATES. GUNCOTTON UNTAMPED.
SOFT WOOD CONCENTRATED CHARGE OR NECKLACE OF GUNCOTTON UNTAMPED.
AUGER HOLES.
SOFT WOOD.
HARD WOOD.
D
HARD WOOD CONCENTRATED CHARGE OR NECKLACE OF GUNCOTTON UNTAMPED.
MASONRY WALLS HAUNCHES OR CROWNS OF ARCHES GUNPOWDER TAMPED.
C
MASONRY PIERS OF BRIDGES. GUNCOTTON UNTAMPED.
HAUNCHES OR CROWNS OF MASONRY ARCHES. GUNCOTTON TAMPED.
B
HAUNCHES OR CROWNS OF MASONRY ARCHES. GUNCOTTON UNTAMPED.
MASONRY WALLS. GUNCOTTON TAMPED.
A
BREADTH.
NOTE STRAIGHT EDGE HELD ON CORRESPONDING SCALES O
BREADTH AND THICKNESS, WILL GIVE CHARGE ON CENTRAL SCA

PLATE XVII.

DEMOLITIONS.