Accompaniment to G.O., No. 1,986 W., dated 23rd August 1880.

EXPERIMENTS WITH DYNAMITE.

No. 381.

From

MAJOR J. L. L. MORANT, R.E.,

Executive Engineer, West Coast Division,

To

THE SUPERINTENDING ENGINEER,

Second Circle, Coimbatore.

SIR,

Order to conduct Experiments.—With reference to Public Works G.O., No. 2,686 W., dated 24th October 1879, I have the honor to submit my report, with plans and tables, of the results of a "careful series of experiments made to elucidate the best method of employing dynamite and its economical value as compared with gunpowder in all the ordinary operations of the department, *e.g.*, removing rock with good or bad faces, in the construction of ghât roads, breaking up and removal of boulders from road surfaces or elsewhere, "getting" rock for the manufacture of road metal, &c."

2. *Experiments how carried out.*—The experiments to be reliable required considerable intelligence in the person prosecuting them and very accurate plans and sections of the demolished rocks both before and after the explosion. For this purpose I placed Sub-Engineer and Conductor Mr. A. Milne in charge of the experiments and gave him full and detailed written instructions as to the manner in which they were to be carried out and the points of inquiry to which his attention was to be directed. Mr. Milne came to me from the Wynaad and was at Mettupálaiyam from January till April doing nothing else but carrying out these experiments. I visited him eight times, and Mr. John Harris, Indian Mining Instructor of Nobel's Explosives Company, visited him twice, remaining with him several days each time. Colonel Sankey, C.B., and yourself also kindly witnessed some of the experiments in April last. Specimens of all the rocks experimented upon were sent to Surgeon-Major George Bidie, M.B., F.L.S., of the Madras Museum, to be classified and described, and their specific gravities were also accurately ascertained. A careful record has also been kept of the cost of boring and of removing the exploded rocks. No effort has in short been spared to obtain, by measured sketches made on the spot by plans, sections, and figured records, the actual facts.

Nothing has been left to guessing or even to approximation. The dynamite used was Nobel's No. 1. The powder was obtained from the Government Factory at Madras and is well known as being the very best of its kind, peculiarly well suited for blasting rocks. The jumpers used for boring were each 1″, $1\frac{1}{8}$″, and $1\frac{1}{2}$″ in diameter.

3. *Extent of Experiments.*—To show the extent of the experiments I may note that eight different descriptions of rock were demolished; 500 lb. of dynamite, 100 lb. of gunpowder, and 800 running yards of fuze were used; 1,200 bore-holes requiring 1,000 lineal yards of boring were made; and 4,300 tons of rock were operated upon at a total cost of Rs. 4,082.

4. *Preliminary Paper on Dynamite attached.*—In order to make the subject more intelligible, especially to those who have never seen or used dynamite, I beg to be allowed to append a paper written for Indian Engineering which contains nearly everything connected with dynamite that a search from amongst the Proceedings of the Institute of Civil Engineers and other reliable books of reference has enabled me to gather. A perusal of the facts contained in that paper will clear the ground for the experiments on which I now propose to enter. To avoid repetition I have purposely omitted very much from this report (such as safety, storage, carriage, &c., of dynamite) which appears in the attached paper, and which otherwise I should have made a point of recording. The first paper and this report ought to be read together.

5. *Experiments how recorded.*—The experiments on dynamite recently conducted near Mettupálaiyam are all recorded in the accompanying twenty-two plans and in record book. The plans and sections are drawn to a scale of 4 feet to the inch, or

$\frac{1}{45}$. The sections are not distorted, the horizontal and vertical scales being the same, and the entries in the record book are numbered consecutively for easier reference. Nearly all the experiments have been abstracted into the Tabular Statement No. I which is attached to this report and which contains all the results arrived at under every heading and in every form that was thought likely to be of use. This table, I trust, needs no explanation, but speaks for itself.

6. *Results on Gneiss Rocks.*—The following abstract gives the results of the employment of dynamite on eight different kinds of rocks per ton and per 100 cubic feet of rock removed, the results per ton being given in ordinary type and those per 100 cubic feet in black type:—

—	Number in the Table I.	Description of Rock.	Weight of Rock per Cubic Feet in Avoirdupois.	Dynamite used in Ounces.	Bore-holes drilled in Lineal Feet.	Number of Men employed in removing the Rock.	Fuze used in Lineal Feet.	Number of Detonators used.	Entire Cost per Ton in Ordinary Type; per 100 Cubic Feet in Black Type.
			LBS.	OZ.	L. FT.	NO.	L. FT.	NO.	RS. A. P.
I.	1, 2, 3, 6 and 9.	Gneiss	184½	1·4	0·8	0·6	0·65	0·4	0 9 0
				11·6	**6·5**	**5·1**	**5·6**	**3·4**	**4 10 2**
II.	4, 7, 8 and 12.	Gneiss (Quartz Feldspathatic with Garnets).	183	2·0	0·9	0·5	0·8	0·5	0 10 5½
				16·2	**7·9**	**4·4**	**6·5**	**4·0**	**5 11 3**
III.	5	Quartzose Gneiss (weathered and containing Garnets).	170	0·4	0·4	0·7	0·4	0·1	5 4 0
				3·0	**3·0**	**5·0**	**3·0**	**0·7**	**2 8 7**
IV.	10	Hornblendic Gneiss inclined to be Schistose.	180	2·3	1·2	0·5	1·4	0·7	0 13 5
				18·8	**10·0**	**4·4**	**11·2**	**6·0**	**6 7 2**
V.	13 to 17	Syenitic Gneiss	181	2·1	0·7	0·5	0·6	0·27	0 8 9
				17·5	**5·4**	**3·8**	**4·3**	**2·3**	**4 6 9**
VI.	20	Dark Gneiss inclined to be Schistose.	185	3·5	1·5	0·8	1·2	0·7	1 1 2
				29·3	**12·8**	**6·4**	**9·7**	**5·9**	**8 13 8**
VII.	18	Do. with bands of Quartz.	192	1·7	0·5	0·3	0·4	0·2	0 5 2
				14·7	**4·3**	**2·7**	**3·2**	**1·6**	**2 12 9**
VIII.	19	Trap	200	4·0	1·0	0·5	0·7	0·3	1 2 6
				38·0	**8·5**	**5·0**	**6·0**	**3·0**	**10 3 8**

7. *Dynamite and Gunpowder compared.*—Taking the experiments altogether we obtain the following results with dynamite and with gunpowder:—

	With Dynamite.	With Gunpowder.
Weight of explosive used per ton of rock blasted do.	0·13 lb.	0·4 lb.
Lineal feet of holes bored do.	0·84 feet.	1·96 feet.
Number of men moving rock do.	0·48 men.	0·9 men.
Lineal feet of fuze used do.	0·70 feet.	1·56 feet.

The proportion of weight of rock loosened to the weight of explosive employed is—

In Dynamite.—18,488 to 1.
In Gunpowder.—5,464 to 1.

Rankine says in gunpowder from 7,000 to 14,000 to 1 in small blasts, and from 4,500 to 13,000 to 1 in great blasts.

But he probably refers to sedimentary rocks and easy rocks like chalk as well as to granite, &c. Rankine also states that in gunpowder from $\frac{1}{2}$ to $\frac{1}{3}$ of a lb. of powder is generally required for each ton of rock removed; our powder experiments give 6·7 oz. or $\frac{3}{8}$ of a pound per ton: in dynamite we see that $\frac{1}{8}$ of a lb. sufficed: and in number 644 of the experiment book the charge was only $\frac{1}{10}$ of a lb. per ton. Hurst gives 3 lb. of powder to every 100 cubic feet of rock blasted. Our experiments in dynamite give 1 lb. of dynamite for the same.

8. In the Mettupálaiyam experiments No. 14 of dynamite and No. 21 of gunpowder in Table No. I are the most similar and comparable. From these two experiments we learn that by using gunpowder and dynamite the following relative proportions resulted in producing equal effects, the price of powder being 10 annas and that of dynamite Rs. $1\frac{1}{2}$ per lb.:—

	Gunpowder to Dynamite.
Explosive charge in weight *per* ton of rock removed ...	1 : 0·5
Bore-holes do.	1 : 0·3
Labor for removing rock after blasting do.	1 : 0·6
Fuze do.	1 : 0·5
Entire cost do.	1 : 0·7
Time do.	1 : 0·5

or, in other words, to produce the same effect on a mass of rock dynamite requires only one-half the quantity of the explosive and of the fuze, one-third the number of bore-holes, three-fifths of the labor for removing the rock after blasting, that powder does, at a saving of three-tenths in the entire cost notwithstanding the price of dynamite being $2\frac{1}{2}$ times the price of powder, and it enables its work to be done in one-half the time.

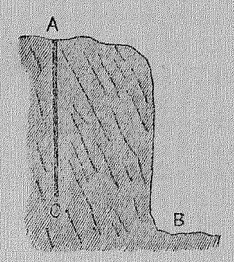
9. In blasting, dynamite shatters the rock much more completely than powder does; powder tears it out in bulky masses; dynamite in slaty slices or splinters. The effect of the explosive force of dynamite also frequently extends very far beyond the seat of the charge, thus assisting succeeding blasts (see No. 1,118 of the record book); dynamite does not generally throw the rock out so far as powder, but it cracks and splits it into more numerous and thinner portions than powder does, thus lightening the labor of disentangling the pieces, and it leaves the rock generally so disintegrated and with such sharp angles as to greatly facilitate its after-removal with the sledge-hammer and crowbar. This is illustrated by the following figures which were obtained from the experiments at Mettupálaiyam:—

—		Dynamite.	Gunpowder.
In every 100 cubic feet of rock blasted.	Rocks shattered by the dynamite and loosened by the powder	78	56
	Rocks thrown out a moderate distance	21	43
	Do. a considerable distance	1	1
		100	100
	and		
In every 100 cubic feet of rock disturbed by the first blasts.	Rock which had to be reblasted	5	20
	Rock removable by hand	62	20
	Do. by crowbars	33	60
		100	100

The peculiar *percussive* effect of dynamite is well illustrated in No. 1,114 of the record book, where the upper portion A was knocked off as it might have been by a hammer.

10. Dynamite does not act in the line of least resistance as powder does; its bore-holes can therefore be made shallower and further apart than those required by powder.

11. *Dynamite how best employed.*—Regarding the best methods of employing dynamite the experiments show that the bore-holes should *not* as a rule be more than 5 feet deep. Dynamite used in deeper holes loosens larger rocks which generally have to be rebored and blasted, unless they are situated at a height and are blown by the explosion across the road-way which it may be intended to open to traffic; in road-making, however, it is often economical to retain stone not immediately wanted, but which subsequently is used up in culverts and walls.



The depth of the bore-holes should, as a rule, be *equal* to the length of the line of least resistance, and their distances apart from one-and-a-half to two times their depth. Exceptions may arise as in the adjoining section, where if the piece ACB had to be removed, and Bc $= d_4$, and Ac $= d$ C. feet, then a 6-foot hole should be bored and exploded with a charge for a 4-foot LLR.

12. Cracks and fissures in the rock blasted are of great importance and should be studied in order to enable the blaster to decide on the position of the bore-holes. *The charge of dynamite should always be laid in a sound piece of rock*, not nearer to a crack, if practicable, than 1 foot.

Fig. 2.
Plan.

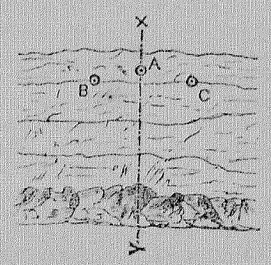
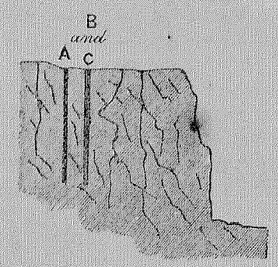


Fig. 3.
Section on XY.



The above plan and section will illustrate this point. The lines in both show the cracks and cleavage in the rocks. The best position for the bore-hole to contain the charge of dynamite is A. At B or C the charge would have to be doubled or even quadrupled, and then the effect might be comparatively feeble. If the cracks between the face of the rock and A (the back) are open, leaving cavities, the effect of an explosion of dynamite in the bore-hole at A would remove less rock than if the rock were quite sound, but, if the cracks are very close, as is not seldom the case, then the results of the explosion will be better than in perfectly sound rock.

13. In using dynamite a large number of bore-holes placed in a group or laid in line, if not further apart than 9 inches, can all be exploded almost simultaneously by the direct ignition of only one of the charges. See Nos. 1,113, 1,114, 1,109, 1,108, 1,060, 1,061, 10,162, and 644 in the record book.

14. When it is desired to shatter rocks by means of dynamite it is absolutely essential *to insure between the dynamite and the rocks operated on a close connection and also to multiply as much as possible the points of contact.* These are conditions of the first importance and should always be borne in mind when using dynamite. For this reason several bore-holes of moderate diameters are preferable to one hole of a larger diameter, no account being taken of the greater convenience and often of economy also in working a smaller jumper. To illustrate this point let us take four holes of any lengths, each one inch in diameter and each loaded to a depth of 4 inches. There will thus be in all a length of 16 inches of bore-hole loaded altogether with 11·72 ounces of dynamite. To hold that quantity of dynamite a two-inch hole must be filled to a depth of 4·37 inches. Now in the case of the four one-inch holes each loaded 4 inches deep, the square surface of contact between the dynamite and the rock will be 50·27 square inches. Whereas, in the case of the one two-inch hole, loaded with the same quantity of dynamite to a depth of 4·37 inches, the surface of contact will be only 27·45 square inches, or little more than one-half the surface in the former case. It is thus clear that, speaking generally, a number of bore-holes, if moderately small, are preferable to a single hole of a larger diameter.

15. In the case of gently-sloping rock with no face, dynamite should be used very much as powder is in such a case only with shallower and fewer bore-holes. As the line of least resistance is not so important in dynamite as in powder, the necessity for sloping the holes is not so great. Nos. 1,157 to 1,173 of the record book show how faces can be formed on sheet rock with gentle slopes. But, if a face be required on a flat rock, sloping holes must be resorted to. Attempts to form a face by numerous shallow holes with small charges and by deep holes near together with heavy charges failed. See Nos. 1,150 to 1,156, 1,144, 1,147, 1,124 to 1,132, 1,119, 1,120 of the record book which illustrate this point.

16. Where a well may have to be sunk through rock, a face may be obtained by drilling 3 holes 9 inches apart in the form of an equilateral triangle, and not more than 4 feet deep, and loading each of them with heavy charges of dynamite. The firing of any one charge will explode the other two. See Nos. 1,037 to 1,069 inclusive of record book for rock-blasting in a well and Nos. 1,053 to 1,056, 1,060 to 1,062, and 1,067 to 1,069 to illustrate the method of blasting several holes together. This method of firing may also sometimes be adopted with advantage in breaking up very large boulders.

17. *Dynamite in getting road metal.*—Owing to the shattering and splitting effect of dynamite on rock, this explosive is peculiarly well fitted for affording assistance in obtaining road metal. The rock, whether in the solid or in boulders, is first blasted in the usual manner, and then such pieces as are too big to be sledge-hammered are bored with fresh holes, one-third the vertical height of the blocks in depth, and charged with one ounce of dynamite to every 4 square feet of least vertical section. The rock is thus shattered into pieces small enough to be readily broken into road metal. All rock on which dynamite is used as an explosive becomes so disintegrated as to make the obtaining from it of road metal a very easy and cheap process. The saving in cost is 40 per cent.

18. *Hasty demolitions with Dynamite.*—Hasty demolition of rocks. Dynamite, unlike gunpowder, enables this to be done by the mere superposition of the explosive on the rock to be broken without using any bore-hole. This method answers but feebly on solid gently-sloping sheet rocks with no face. In such cases this method cannot be advocated; it is both cheaper and quicker to bore holes. Examples of obtaining a face on sloping rocks will be found in Nos. 1,149, 1,157, and 1,172 of the record book. But where boulders or partly-decomposed fissured rocks have to be very rapidly removed, the dynamite can be merely laid on the surface of the rock without any bore-hole, covered up and exploded with the desired effect. The only objection to this method is that a much larger quantity of the explosive must be used than if a hole or two, however shallow, be first bored and filled with the dynamite and then exploded. In fact it can only be justified where time is of much greater importance than a wasteful expenditure of the explosive. See Nos. 1,086, 1,087, 1,088, 1,089, and 1,090 of the record book.

19. If an hour or two can be secured, the best plan is to bore close together several shallow holes (made as deep as the time allows); to fill them with dynamite connect the charges with other cartridges of dynamite pressed close against the rock, to fix the primer, detonators, and fuze in the centre of all the holes, to cover up with moist clay flat heavy stones, &c., and to fire the charge. The depth of the bore-holes, if there be time, should be about one-fifth the vertical height of the rock or boulder and about 3 feet apart according to circumstances. The charges should be calculated at 1 oz. to every square foot of vertical section. See Nos. 1,108, 1,109, 1,113, and 1,114 of the record book.

20. Holes of various shapes (oblong, square, crosswise) were chiselled into the surface of large boulders, filled with dynamite, covered with clay and exploded. But the results they gave were not so good as with which bore-holes four times deeper than the rectangular holes; chiselling the rock is more expensive and takes a longer time than boring, while the explosive effect is not increased. See Nos. 1,115 and 1,116 and compare them with Nos. 1,108 and 1,113 of the record book.

21. Where time does not admit of any holes being made, the rock should be first carefully examined to discover some crevice or hollow place near its centre in which the dynamite can be laid. This spot should be first washed clean of all dirt, dust, and rock debris, the dynamite should be removed from its parchment wrapper and be pressed down with the fingers protected by a glove into the seat of the charge, advantage being taken of any weak lines in the rock along which it should be laid. The charge should not be heaped up higher than the depth of 2 cartridges (2 inches). The primer detonator and fuze being inserted, the whole charge should be well covered up to as great a depth as possible with moist clay, earth, flat heavy stones, &c., and then exploded.

22. From numerous experiments it was found that two ounces of dynamite to every square foot of least vertical section sufficed to break up boulders of gneiss rock in this way. The manner of laying the dynamite on the rock and the nature of the rock itself of course affect this proportion. If, for example, the rock is firm, but has a tendency to break up into regular solids, as quartz and trap often do, or if a hole in the rock favors the placing of the charge, then the dynamite may be reduced.

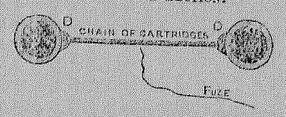
23. But circumstances may necessitate the dynamite being exploded on the rock without any covering at all. In this case it must also be applied exactly as above described, but the charge must be increased to 3 or 4 ounces per square foot of least vertical section.

24. *Dynamite on Field Service.*—Hasty demolition of gates, &c. The explosion of dynamite is almost instantaneous and to a certain extent and under certain conditions so local that when not confined its effect, though extraordinarily severe, acts only on one single part of the object against which it is placed. This feature of dynamite is well illustrated by an experiment made by Mr. John Harris at Beypore. Two vertical hollow cast-iron columns (supporting the beam of an engine), each one inch thick, 9 inches in diameter and 4 feet apart, were experimented on with dynamite in the following way: $1\frac{1}{4}$ lb. of dynamite was tied to one side of each column in a bunch, and these 2 charges were connected by a chain of dynamite cartridges and exploded. Four holes, two in each, were simply knocked through the two hollow columns according to the sketch just as if a cannon ball had passed completely through both of them, but otherwise the columns were absolutely uninjured and remained standing unmoved. Thus a 5-lb. packet of dynamite laid against the gate of a fortress and exploded would simply knock out a curvilineal hole about 2 or feet square. But, if the same quantity of dynamite was laid against the middle of the gate in flat bags, say of tin or cloth, so that the thickness of the charge did not exceed one inch, the gate would probably be shattered from top to bottom.

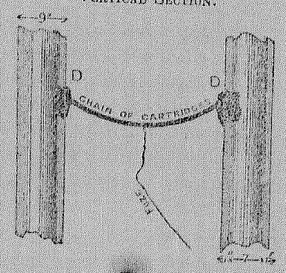
SECTION THROUGH PILLARS.

FIG. 4.

HORIZONTAL SECTION.



VERTICAL SECTION.

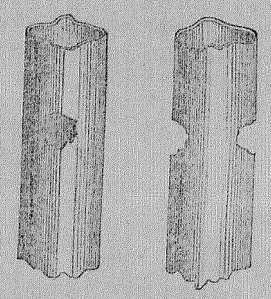


D. DYNAMITE CHARGE.

FIG. 5.

ENLARGED ELEVATION OF PILLARS.

FRONT ELEVATION. SIDE ELEVATION.



(9" DIAMETER.)

25. *Dynamite Tamping.*—Different materials were tried in tamping the boreholes with the following results:—

Clay was found to be the best material for tamping in all sized holes. It was used quite dry and in a fine powder. The first 6 inches of the tamping next the charge were gently pressed with a wooden rod, and the remainder was poured into the bore-hole with the hand in a small stream and sharply punned with a rod.

Sand was used in tamping the bore-holes in precisely the same way as clay was used. With deep holes it was found to be inferior, but in smaller holes it was decidedly inferior to clay, and in very small holes (about a foot deep) it appeared to have no effect at all.

Water as tamping appeared to be as good as any other in small bore-holes up to about 2 feet, but in deeper holes it was inferior to clay and sand. Water is very convenient in misfires, as the fuze and primer can be easily removed and a fresh fuze and primer re-inserted. But misfires occur so seldom when Bickford's fuze is employed that this advantage is hardly felt; during the whole of our experiments there was only one misfire. Water-tamping moreover is more expensive and takes up more time than dry tamping; the fuze used with water-tamping costs double the ordinary fuze; and, after the detonator is secured to the fuze, the junction must be made water-tight with grease or wax. It cannot be used in holes that are cracked. Water-tamping should only be used in wet places or when the explosion is effected by an electric battery. When a battery is used a misfire is more likely to occur than when Bickford's fuze is employed, and thus water-tamping allows of the fuze being easily removed and a fresh one being put in.

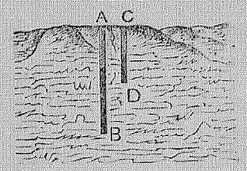
26. When *no tamping* was used the results were scarcely inferior to those obtained with tamping. When the holes are very shallow (9 inches to 12 inches deep) tamping is unnecessary.

27. On the whole it matters little whether clay, fine sand, or dust (such as worn-down road materials) is used for tamping; at all events it is not necessary to go to much trouble to procure clay.

28. Speaking generally the tamping is a weak point in shallow holes. In holes of 1 and $1\frac{1}{2}$ inch diameter a depth of $2\frac{1}{2}$ feet of tamping is quite sufficient. A greater depth of tamping does not augment the effective power of the explosive while a less depth causes a loss of power through the bore-hole.

29. *Misfires.*—When a misfire occurs with water-tamping, it is only necessary to remove the fuze and primer from the hole and put in a fresh one; but when the stiff tamping is employed in case of a misfire, the tamping must on no account be removed; this would involve a great danger. A fresh hole must be bored not nearer than 6 inches to the old one and be loaded and exploded in the ordinary way. The explosion of the charge in the new hole will most likely explode the first charge. But should the first hole be one of considerable depth, as AB, it will only be necessary to make the new hole 6 inches lower than the top of the charge of dynamite in the old hole as CD. The explosion of the charge in CD will fire that in AB.

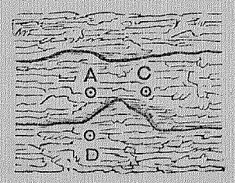
FIG. 6.



30. When the rock is vertically stratified or is likely to crack in one direction more than in another, the new hole should be bored on this weakest line. In the adjoining sketch-plan the lines show the direction in which the rock most readily splits. C is then the proper position for the new bore-hole with respect to A, the old hole. If C were bored at D, the chances of its exploding A would be considerably diminished.

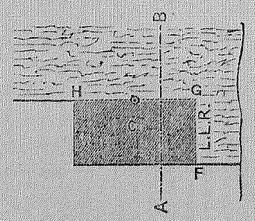
FIG. 7.

PLAN OF ROCK.



31. *Explosive Charges of Dynamite.*—Formula for calculating charges of dynamite. In treatises on rock-blasting the usual direction is that the charge should vary with the line of least resistance (LLR) cubed, or, in other words, with the rough contents of the mass of rock to be blasted. But where the charges and the LLRs are comparatively small, this rule does not hold good, at least so far as dynamite is concerned, and probably in the case of gunpowder also. We discovered this fact in this way: We took, say, a 3-foot LLR and loaded numerous corresponding bore-holes with various charges until one was found which exactly answered with the co-efficient. On the $(LLR)^3$ thus obtained we calculated other charges for holes with LLRs both less and greater than 3 feet. We always found that where the LLRs were less than 3 feet the charges thus calculated were too low, while with LLRs greater than 3 feet they were too high. From these results, which were tested over and over again, it seems clear that the explosive charges, or, which is the same thing, the resistance to the charges do not vary as the $(LLRs)^3$, or as the *mass of rock operated upon taken alone.* An investigation of the problem seems to show that the *square surfaces of the rock* from which the mass is torn $(LLRs)^2$ should also be considered, and that these affect the result much more than the mass.

FIG. 8.

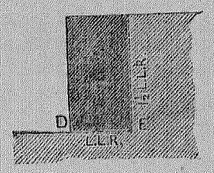


32. I will now endeavour to solve this problem.

Let us take the most common case of rock-blasting with two clear faces and assume the depth of the bore-hole to be one-and-a-half times the line of least resistance, or LLR, and that the rock will facture evenly on the three surfaces DE, FG, GH (plan and section), shown by the red dotted lines. The explosive will therefore *fracture* the rock on these three surfaces and also push along the mass C on DE, *i.e.*, overcome the *friction* of the mass C on DE (see section). To put this into a formula, let us call the whole explosive Force P, the fracturing Force R^a, and the frictional Force R^f.

FIG. 9.

SECTION ON A.B.



Then $P = R^a + R^f$ ... ... (1)

Applying this formula to the above figures we find—

$$R^a = \overset{\text{Area of 3 surfaces.}}{6{\cdot}5 \times (LLR)^2} \times r \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where r is the resistance offered by one square foot; and

$$R^f = W \times \cos.\ 350 \text{ (angle of friction)}$$

$$= \overset{\text{Mass C.}}{2 \times 1 \times 1\tfrac{1}{2}\ (LLR)^3 w} \times {\cdot}82$$

$$= \overset{\text{nearly}}{2{\cdot}5\ (LLR)^3 w} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where w is the weight of one cubic foot of rock blasted.

Substituting (2) and (3) in (1)

$$P = 6{\cdot}5\ (LLR)^2 r + 2{\cdot}5\ (LLR)^3\ w$$

$$\text{or } P = 2{\cdot}5\ (LLR)^2 \times \left\{2{\cdot}6 \times r + (LLR) w\right\} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

and the formula will take this form wherever the direction of the fractures may be and whatever angle of friction may be assumed.

Taking $w = 180$ lb. avoirdupois and $r = 432{,}000$ lb. avoirdupois and substituting

$$P = 2{\cdot}5\ (LLR)^2 \times \left\{2{\cdot}6\ (432{,}000) + 180\ (LLR)\right\}$$

$$\text{or } P = 540\ (LLR)^2 \times \left\{\overset{\text{Tearing Force.}}{6240} + \overset{\text{Frictional Force.}}{(LLR)}\right\} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

33. Now the explosive charge is obviously proportional to the disruptive force P. Taking therefore LLRs from 1 to 10 feet, and omitting the common factor 540 $(LLR)^2$ from equation 5, we obtain—

	Feet.		Tearing Force due to Area.		Fractional Force due to Contents.		Tearing Force due to Area.		Fractional Force due to Contents.
Charge for ...	...	1	varies as	6,240	+	1	or as	1	+ ·0016
" ...	...	2	"	6,240	+	2	"	1	+ ·0032
" ...	...	3	"	6,240	+	3	"	1	+ ·0048
" ...	...	4	"	6,240	+	4	"	1	+ ·0064
" ...	...	0	"	&c.	"	&c.	"	0	" "
and charge for ..	...	10	"	6,240	+	10	"	1	+ ·016
" " ...	...	100	"	6,240	+	100	"	1	+ ·16

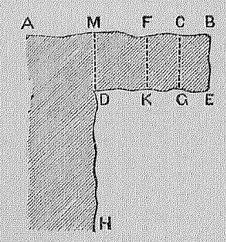
thus agreeing with what was discovered experimentally, viz., that the area offers the greatest proportionate resistance in small, while the mass does so in large blasts. It is not for a moment supposed that the above figures are absolutely correct, or that they give the correct proportions of the influence on the charge of the forces due to area $(LLR)^2$ and to contents $(LLR)^3$. But it is believed that they accurately indicate, in calculating the required explosive charge, the preponderating influence of the former element.

34. That the area may the most affect one problem while the contents affect another is shown by the following case :—

A boulder quite free at the bottom with a *vertical* bore-hole down its centre can only resist fracture by means of its *cohesion*, and here the charge to explode it must vary as the area $(LLR)^2$. But if the bore-hole were drilled *horizontally* into the boulder, then the charge might be affected more by the weight $(LLR)^3$ than by the area, and, if the mass was very large, the resistance due to the weight or $(LLR)^3$ would greatly preponderate.

35. Or we may take a case in which the contents of the rock facilitates the blasting of it and acts inversely on the calculation for the explosive charge. *For example*, supposing AE to be a piece of rock projecting from the main mass AH and that CE is required to be blasted off; the requisite charge would here be obviously less than if DE were supported, because CE would by its weight $(LLR)^3$ assist the explosive in fracturing the rock at CG. Again, if the piece to be blasted extended to F (FBEK), then the explosive charge required would be less than that necessary for only CBEG, because the mass assisting the fracture would be greater while the sectional area remained very much the same. And in the example given in figure 10 the explosive charge diminishes until a point is reached (say at DM), when the weight of the mass ME causes a rupture at MD by its own weight above without any explosive.

Fig. 10.
Section.



36. With the above consideration, in calculating explosive charges of dynamite for rock under various conditions, the equation ought therefore to assume the following form: —

$$W = A\ (LLR)^2 + B\ (LLR)^3 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

W being the weight of the charge in ounces avoirdupois, and A and B co-efficients to be determined by experiment.

In a case like that shown in figure 10 the equation would take this form—

$$W = A\ (LLR)^2 - B\ (LLR)^3 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

But this not at all common in practice.

37. We have taken formula (6) and by numerous direct experiments have applied it to four common cases of rock blasting usually met with in practice. The value of the co-efficients A and B have been found by experiment on the gneiss rocks which were blasted near Mettupálaiyam; and the results have been embodied in Table II. In other kinds of rocks a few experimental trials must be first made, and a similar table can then be constructed for them.

38. At the end of Table II will be found explosive charges for gneiss boulders exploded with deep and shallow bore-holes, with no holes at all, and with dynamite laid upon them with no covering. Table II has been tested over and over again during the experiments at Mettupálaiyam, and is believed to be very accurate.

39. Of course, in practice, the simple conditions, to meet which the charges in Table II have been calculated, are seldom exactly met with. The rocks generally present a combination of those conditions. In such cases the charges must be taken as a mean between the given conditions; and judgment must be exercised. No more exact a table is possible. Moreover, it is seldom that, in any charge, less than a cartridge or than a primer is used. A cartridge weighs 2 or $2\frac{1}{3}$ ounces and a primer $\frac{3}{4}$ of an ounce. Thus, where the table a charge of 19·4 ounces is entered, 20 ounces or 9 or 10 cartridges would, of course, be put into the hole; or where 0·4 ounce is entered a primer ·67 ounce would be used. A table to suit the cartridges might be formed in this way. Taking the commonest case of one clear face and the two sized cartridges supplied we obtain the following :—

Line of Least Resistance in feet.	Explosive charges in Ounces Avoirdupois.	Number of Dynamite Cartridges.	
		No. of Cartridges 8 to the lb., 2 ounces = 1 Cartridge.	No. of Cartridges 7 to the lb., $2\frac{1}{3}$ ounces = 1 Cartridge.
LINEAL FEET.	OUNCES.	NUMBER OF CARTRIDGES.	NUMBER OF CARTRIDGES.
1	$\frac{3}{4}$	Primer.	Primer.
$1\frac{1}{2}$	$1\frac{1}{2}$	2 Primers.	2 Primers.
2	3	1 Cartridge 1 P.	1 C. + P.
$2\frac{1}{2}$	$5\frac{1}{4}$	3 " + P.	2 + P.

Line of Least Resistance in feet.	Explosive charges in Ounces Avoirdupois.	Number of Dynamite Cartridges.	
		No. of Cartridges 8 to the lb., 2 ounces = 1 Cartridge.	No. of Cartridges 7 to the lb., $2\frac{1}{3}$ ounces = 1 Cartridge.
LINEAL FEET.	OUNCES.	NUMBER OF CARTRIDGES.	NUMBER OF CARTRIDGES.
3	$8\frac{1}{3}$	4 Cartridegs + P.	3 + P.
$3\frac{1}{2}$	$12\frac{1}{4}$	6 ,, + P.	5 + P.
4	$17\frac{1}{2}$	9 ,, + P.	8 + P.
$4\frac{1}{2}$	$23\frac{3}{4}$	12 ,, + P.	10 + P.
5	$31\frac{1}{4}$	16 ,, + P.	14 + P.
$5\frac{1}{2}$	$40\frac{1}{3}$	20 ,, + P.	17 + P.
6	51	25 ,, + P.	22 + P.
$6\frac{1}{2}$	$63\frac{1}{2}$	32 ,, + P.	28 + P.
7	78	39 ,, + P.	34 + P.
$7\frac{1}{2}$	94	47 ,, + P.	40 + P.
8	112	56 ,, + P.	48 + P.
$8\frac{1}{2}$	133	67 ,, + P.	57 + P.
9	156	78 ,, + P.	67 + P.

40. In Table II two columns have been provided,—one giving the explosive charge in decimals of a lb., and the other the fraction of the $(LLR)^3$ resulting from that charge. It will be seen that in shallow bore-holes the fraction is much larger than in deeper holes. To compare these charges with those of gunpowder as recorded in various works of reference I may here add that,

Colonel Schun, R.E., in Ceylon, blasted cracked gneiss with gunpowder using small holes 18 inches deep, and his charges were *in lb.*

$$\frac{(LLR)^3}{C} \quad \ldots \quad (8)$$

In closely-packed limestone near Attock with powder made by the officer in charge of the work, the lines of least resistance being 20 feet and downwards—

The charges in lb. were :—

$$\frac{(LLR)^3}{10} \text{ and } \frac{(LLR)^3}{15} \quad \ldots \quad (9)$$

The former too violent, the latter too weak. At Caxton near Chatham in chalk rocks rather more than—

$$\frac{(LLR)^3}{27} \text{ and } \frac{(LLR)^3}{20} \quad \ldots \quad (10)$$

were the charges used in pounds.

Rankine gives in lb. the charge for powder—

$$\frac{(LLR)^3}{10} \text{ to } \frac{(LLR)^3}{32} \quad \ldots \quad (11)$$

In Table No. II for dynamite the charge in lb. varies from—

$$\frac{(LLR)^3}{32} \text{ to } \frac{(LLR)^3}{116} \quad \ldots \quad (12)$$

41. Nobel's No. 1 Dynamite Cartridges are from $\frac{7}{8}''$ to $1''$ in diameter, $3\frac{1}{2}''$ long, and each weighs 2 ounces and $2\frac{1}{3}$ ounces respectively ; they are intended to be used in 1 inch holes. Where holes of larger bore are drilled the dynamite should be taken out of its parchment wrapper, dropped into the hole and squeezed with the wooden rod so as to completely fill the hole.

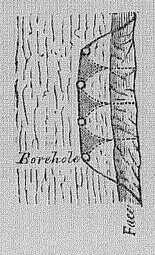
The following table will, it is hoped, be useful in employing dynamite :—

Diameter of the bore hole.	Dynamite in one lineal inch of hole.		Dynamite in one foot of hole.		Depth of hole to contain one lb. of dynamite.
	AVOIRDUPOIS.		AVOIRDUPOIS.		
INCHES.	LBS.	OZS.	LBS.	OZS.	INCHES.
1	0	0·670	0	8·040	23·880
$1\frac{1}{2}$	0	1·507	1	2·084	10·617
2	0	2·682	2	0·184	5·966
$2\frac{1}{2}$	0	4·189	3	2·268	3·820
3	0	6·032	4	8·384	2·652

42. *Firing by Electricity.*—The method of exploding charges of dynamite by means of electricity should generally be adopted except in isolated small holes; it should generally be used when the holes are from 4 to 6 feet deep, as then the quantity of material blasted will be considerable, because the loosening of the whole rock will be more complete than if each bore-hole were fired separately ; thus the whole cost of removing the blasted material will be considerably reduced. It requires more intelligence than is usually possessed by a maistry to fire charges by electricity, and the fuzes used with the battery are expensive, costing Rs. 5 per dozen. But any Overseer ought to be easily able to use a battery. Holes to be fired simultaneously should be so situated as to cut into one another when exploded, thus assisting each other in doing the work. One advantage of simultaneous firing is that it matters little if one hole is under-charged and another over-charged, because all the holes may be considered as acting together and generating one explosion ; the hole that may be over-charged thus assists that which is under-charged.

Fig. 11.

Plan of Rock with face.



The *full red* lines in the Sketch in Fig. 11 show the probable line of fracture with simultaneous firing, and the dotted red lines show the lines of fracture when the holes are exploded separatively. It will be seen that each charge has much more work to do when fired independently than when 3, 4, or 5 holes are exploded simultaneously and that the blasting of the rock is not so complete, leaving the portions shaded red without throwing them out. Since the charges of dynamite have not so much work to do when fired simultaneously as they have when separately fired, they may be somewhat less than when fired independently, thus saving in dynamite.

Misfire being more likely to happen with electricity than with Bickford's fuze, water tamping should always be used when firing by electricity, to enable the fuze to be removed from the bore-hole in the case of a failure to explode. Should any hole miss fire, the electric fuze should not be removed until after another trial has been made to explode it with the battery ; the second trial will, as a rule, be found to succeed, as misfires are more often due to a weak current and imperfect insulation than to any other cause. The simultaneous exploding of holes will often be very useful in sinking and deepening wells, because the material is so much tied in that it can only be got out by firing a number of holes at one time. Even when the holes are sloping good results can best be obtained by simultaneous explosions.

Nobel's Company supply magnetic exploders to fire six holes at once at a cost of Rs. 200 each.

43. *Dynamite should supersede powder.*—In conclusion it appears clear, from the experiments herein recorded, that dynamite ought every where in India to supersede gunpowder in all such operations as those for which powder is usually now employed, and which are indicated in the first paragraph of this report. But, in quarrying for stone for building, gunpowder seems preferable, owing to the shattering and splitting effect of dynamite, which, if used for such a purpose, would probably injure more stone than it threw out in a second state.

44. *Mr. Milne's service acknowledged.*—I cannot conclude this report without very cordially acknowledging the great assistance cheerfully afforded me by Conductor and Sub-Engineer Mr. A Milne, his aptitude in surveying and levelling, and skill in drawing have been of the greatest use, and he has zealously and intelligently conducted the experiments to my entire satisfaction.

TABLE No. I.

PUBLIC WORKS DEPARTMENT, GOVERNMENT OF MADRAS.

2ND CIRCLE. NILGIRI SUB-DIVISION. WEST COAST DIVISION.

Results of Experiments with DYNAMITE *and* GUNPOWDER *on Rock on the Kótagiri Road near Mettupálaiyam.*

Number of Rock and Plan.	Description of Rock.	Rock Blasted and Removed.			Material used for Blasting.				Bore-hole varying in Diameter from 1 inch to 1½ inches.		Number of Men employed in removing Rock after blasting.	Total Cost of boring, blasting, and removing Rock.	Record of Results per Ton of Rock removed—in black. Per 100 Cubic Feet of Rock removed—in red.							Remarks on each Experiment.	General Remarks.
		Weight Per Cubic Foot.	Number of Cubic Feet.	Number of Tons.	Dynamite.	Gunpowder.	Fuze.	Detonators.	Number of Holes.	Total Depth in Feet.			Dynamite.	Gunpowder.	Bore-hole.	Men employed in removing rock.	Fuze.	Detonators.	Cost.		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	DYNAMITE.	LB.	FT.	TONS.	OZS.	OZS.	R. FT.	NO.				RS. A. P.	OZS.	OZS.	R. FT.	NO.	R. FT.	NO.	RS. A. P.		
1	Gneiss (quartz feldspathic with garnets) free from decay and not much cracked.	183	3,378	275½	606	..	148	86	86	197	143	155 0 0	2·2 **18·0**	.. ..	0·7 **6·0**	0·5 **4·2**	0·5 **4·3**	0·3 **2·5**	0 9 0 **4 9 5**	The rock blasted had to be removed across a road 20 feet wide and then allowed to roll down the hill side.	In no case had the rock blasted to be removed to a higher level than where blasted, except in Nos. 20 and 22. Tools and supervisions are not included in the cost, as they are common to all the experiments and do not affect the comparison. The rate for any district may be obtained from columns 14 to 19, and the plans will show the nature of the rock, face, and description of work done.
2	Gneiss free from decay but a good deal fissured.	185	2,298	190	264	..	80	47	47	113	97	89 1 4	1·4 **11·5**	.. ..	0·6 **4·9**	0·4 **4·2**	0·4 **3·5**	0·3 **2·0**	0 7 6 **3 13 9**	The high face and fissures of this rock facilitated blasting very much.	
3	Gneiss (outcrop of two boulders).	185	58	4·8	6½	..	5	3	3	4·75	2	2 12 0									
4	Gneiss (quartz feldspathic with garnets) very much fissured like a number of boulders well packed.	183	806	66	92	..	40	26	26	47	29	33 0 0	1·4 **11·2** 1·4 **11·5**	.. ..	1·0 **8·2** 0·7 **5·9**	0·4 **3·4** 0·4 **3·6**	1·0 **8·6** 0·6 **5·0**	0·6 **5·2** 0·4 **3·2**	0 9 2 **4 11 10** 0 8 0 **4 1 6**	The rock blasted had to be moved across the road and then allowed to roll down the hill side.	
5	Quartzose gneiss (weathered and containing garnets) a boulder on the surface of the ground.	170	138	10½	4	..	4	1	1	4	7	3 8 0	0·4 **3·0**	.. ..	0·4 **3·0**	0·7 **5·0**	0·4 **3·0**	0·1 **0·7**	0 5 4 **2 8 7**	The smallness of the cost is due to the rock being a boulder free at bottom; the large number of men employed in removing the rock is incorrect; the maistry had no means of knowing the *exact* number of hours coolies were employed on small works of this kind.	
6	Gneiss very much fissured in some parts and fairly sound in others; the fissures were filled with earth.	185	1,632	135	147	..	54	29	29	60	78	56 10 6	1·1 **9·2**	.. ..	0·4 **3·6**	0·6 **4·8**	0·4 **3·3**	0·2 **1·8**	0 6 9 **3 7 6**	The low rate in this case is due to a good deal of the rock having been removed without blasting.	
7	Gneiss (quartz feldspathic with garnets) very much cracked and fissured surface decayed.	183	376	30¾	91	..	38	24	24	43	29	32 0 0	3·0 **24·2**	.. ..	1·4 **11·4**	0·9 **7·7**	1·2 **10·3**	0·8 **6·5**	1 0 6 **8 8 2**	The cost is high on account of the face being low; the quantity of rock removed small, and the fissures so situated as to require a great many bore-holes.	
8	Gneiss (quartz feldspathic with garnets) outcrop of boulders.	183	175	14	20	..	10	7	7	11	4	7 0 0									
9	Gneiss boulders partly buried in the ground.	183	85	7	12¾	..	6	4	4	8	7	5 8 0	1·4 **11·4**	.. ..	0·8 **6·3**	0·3 **2·3**	0·7 **6·0**	0·5 **4·0**	0 8 0 **4 0 0**		
10	Hornblendic gneiss inclined to be schistose; a good deal fissured with sound interior.	180	253	20¼	47	..	28	15	15	25	11	16 5 6									
11	Gneiss (quartz feldspathic with garnets) a little cracked but free from decay.	183	524	43	116	..	49	27	27	65	26	39 0 0	1·8 **14·7** 2·3 **18·8**	.. ..	1·1 **9·4** 1·2 **10·0**	1·0 **8·2** 0·5 **4·4**	0.8 **7·0** 1·4 **11·2**	0·6 **4·7** 0·7 **6·0**	0 12 7 **6 7 6** 0 13 5 **6 7 2**		
12	Gneiss (quartz feldspathic with garnets) with large fissures, but the parts between the fissures sound and free from decay.	183	1,082	89	112	..	43	27	27	55	39	38 15 0	2·7 **22·0**	.. ..	1·5 **12·5**	0·6 **5·0**	1·1 **9·4**	0·6 **5·2**	0 14 6 **7 7 1**	The cost is rather high on account of the face being shallow and the footings in front of the main mass of rock difficult to remove with their numerous vertical cracks.	
													1·3 **10·3**	.. ..	0·6 **5·1**	0·4 **3·6**	0·5 **4·0**	0·3 **2·5**	0 6 9 **3 9 6**	The cost in this case is low on account of the high face and large fissures.	

Results of Experiments with DYNAMITE *and* GUNPOWDER *on Rock on the Kótagiri Ro*

Number of Rock and Plan.	Description of Rock.	Rock Blasted and Removed.			Material used for Blasting.				Bore-hole varying in Diameter from 1 inch to 1½ inches.		Number of Men employed in removing Rock after blasting.	Total Cost of boring, blasting, and removing Rock.	Record of Results Per 100 Cubi		
		Weight per Cubic Foot.	Number of Cubic Feet.	Number of Tons.	Dynamite.	Gunpowder.	Fuze.	Detonators.	Number of Holes.	Total Depth in Feet.			Dynamite.	Gunpowder.	Bore-hole.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	DYNAMITE—*Cont.*	LB.	FT.	TONS.	OZS.	OZS.	R. FT.	NO.				RS. A. P.	OZS.	OZS.	R. F
13	Syenitic gneiss not much cracked and free from decay.	181	1,169	95	233	..	56	30	30	75	50	62 0 0	2·4 19·9	.. ..	0 6
14	Syenitic gneiss very little cracked and free from decay.	181	3,198	258	684	..	180	86	86	237	124	182 0 0	2·6 21·4	.. ..	0 4
15	Syenitic gneiss, a good deal cracked but free from decay.	181	1,132	91	245	..	64	37	37	83	57	65 8 6	2·7 21·7	.. ..	0 9
16	Syenitic gneiss almost quite sound.	181	3,782	307	383	..	80	46	46	105	106	102 0 0	1·2 10·1	.. ..	0 2
17	Syenitic gneiss with a few large fissures, otherwise quite sound.	181	5,680	459	832	..	202	106	106	257	162	213 0 0	1·8 14·6	.. ..	0 4
18	Gneiss with bands of quartz quite free from decay with cracks and a few fissures.	192	8,754	750	1,294	..	280	143	143	379	238	245 4 0	1·7 14·7	.. ..	0 4
19	Trap cracked and cleaned; very firm and free from decay.	200	204	18	76	..	12	6	6	17¼	10	19 12 0	4·0 38·0	.. ..	1 8
20	Dark gneiss inclined to be schistose; somewhat cracked and fissured but free from decay.	185	2,157	178	632	..	210	126	126	276	138	191 0 0	3·5 29·3	.. ..	1
									TOTAL.						
	Totals ..	..	36,881	3,042	5,897	..	1,589	874	874	2,062	1,357	1,559 4 10	2·15 16·77	.. ..	6
	GUNPOWDER.														
21	Syenitic gneiss free from decay with a few light cracks.	181	1,500	121	..	687	190	..	94	233	108	133 2 0	.. ..	5·7 45·8	
22	Dark gneiss inclined to be schistose; somewhat cracked and fissured but free from decay.	185	1,089	90	..	697	140	..	59	181	81	108 9 0	.. ..	7·7 64·0	
									TOTAL.						
	Totals ..	..	2,589	211	..	1,384	330	..	153	414	189	241 11 0	.. ..	6·7 54·9	1

OOTACAMUND,
6th July 1880.

(Signed) H. R. MEAD, Major, R.E.,
Superintending Engineer.

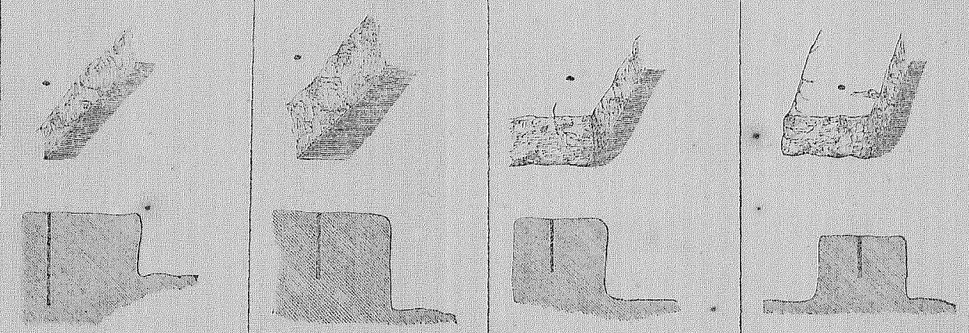
Results of Exp

Number of Rock and Plan.	Description of Rock.	Rock Blasted and Removed. Weight per Cubic Foot.	Number of Cubic Feet.	Number of Tons.
1	2	3	4	5
	Dynamite—*Cont.*	LB.	FT.	TONS.
13	Syenitic gneiss not much cracked and free from decay.	181	1,169	95
14	Syenitic gneiss very little cracked and free from decay.	181	3,198	258
15	Syenitic gneiss, a good deal cracked but free from decay.	181	1,132	91
16	Syenitic gneiss almost quite sound.	181	3,782	307
17	Syenitic gneiss with a few large fissures, otherwise quite sound.	181	5,680	459
18	Gneiss with bands of quartz quite free from decay with cracks and a few fissures.	192	8,754	750
19	Trap cracked and cleaned; very firm and free from decay.	200	204	18
20	Dark gneiss inclined to be schistose; somewhat cracked and fissured but free from decay.	185	2,157	178
	Totals ..	..	36,881	3,042
	Gunpowder.			
21	Syenitic gneiss free from decay with a few light cracks.	181	1,500	121
22	Dark gneiss inclined to be schistose; somewhat cracked and fissured but free from decay.	185	1,089	90
	Totals ..	..	2,589	211

Ootacamund,
6th July 1880.

TABLE No. II.

Explosive Charges of Dynamite in Ounces Avoirdupois to blast Gneiss Rocks under the various conditions shown. Charges calculated from the Formula: W
Square Feet of least Vertical Section.

Explosive employed.	Solid attached Rocks.	Loose detached Rocks.
	ILLUSTRATIONS.	
		
	Different conditions of Rock Blasting.	Different conditions of Boulder Blasting.
	Only one Face and that not clear; footings of Rock requiring bore holes to be below bottom of Face.	Only one clear Face; bottom of bore-hole being above foot of Face of Rock.	Two clear Faces.	Three clear Faces.	Vertical Boulder
	Formula with varying Co-efficients.	$W = A\,(L.L.R.)^2 + B\,(L.L.R.)^3$ $A = 1 : B = \frac{1}{6}$ W = Charge in Ounces.	$W = A\,(L.L.R.)^2 + B\,(L.L.R.)^3$ $A = \frac{1}{10} : B = \frac{1}{6}$ W = Charge in Ounces.	$W = A\,(L.L.R.)^2 + B\,(L.L.R.)^3$ $A = \frac{1}{12} : B = \frac{1}{5}$ W = Charge in Ounces.	$W = A\,(L.L.R.)^2 + B\,(L.L.R.)^3$ $A = \frac{1}{3} : B = \frac{1}{12}$ W = Charge in Ounces.	Boulders.

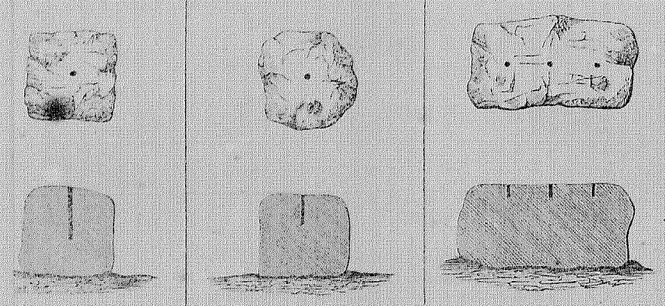
	Lines of Least Resistance or L.L.Rs. in Lineal Feet.	Explosive Charges. Avoirdupois.		Fraction of $(L.L.R.)^3$ in lb.	Explosive Charges. Avoirdupois.		Fraction of $(L.L.R.)^3$ in lb.	Explosive Charges. Avoirdupois.		Fraction of $(L.L.R.)^3$ in lb.	Explosive Charges. Avoirdupois.		Fraction of $(L.L.R.)^3$ in lb.	Area of Least Vertical Section in Square Feet.	One O every 4
		ozs.	lb.		ozs.	lb.		ozs.	lb.		ozs.	lb.		sq. ft.	
Nobel's Dynamite No. 1.	1	$1\frac{1}{4}$	·08	$\frac{1}{12}$	$\frac{3}{4}$	·04	$\frac{1}{25}$	$\frac{1}{2}$	·03	$\frac{1}{33}$	$\frac{1}{2}$	·03	$\frac{1}{33}$	..	
	$1\frac{1}{2}$	3	·17	$\frac{1}{50}$	$1\frac{1}{2}$	·09	$\frac{1}{56}$	$1\frac{1}{2}$	·08	$\frac{1}{42}$	1	·06	$\frac{1}{54}$	2	
	2	$5\frac{1}{4}$	·33	$\frac{1}{32}$	3	·19	$\frac{1}{25}$	$2\frac{1}{2}$	·16	$\frac{1}{30}$	2	·13	$\frac{1}{64}$	4	
	$2\frac{1}{2}$	9	·56	$\frac{1}{18}$	$5\frac{1}{4}$	·33	$\frac{1}{18}$	$4\frac{1}{2}$	·27	$\frac{1}{18}$	$3\frac{1}{4}$	·2	$\frac{1}{78}$	8	
	3	$13\frac{1}{2}$	·84	$\frac{1}{12}$	$8\frac{1}{2}$	·52	$\frac{1}{12}$	7	·43	$\frac{1}{14}$	5	·31	$\frac{1}{96}$	12	
	$3\frac{1}{2}$	$19\frac{1}{2}$	1·21	$\frac{1}{8\cdot5}$	$12\frac{1}{4}$	·76	$\frac{1}{10}$	10	·61	$\frac{1}{16}$	$7\frac{1}{4}$	·45	$\frac{1}{128}$	16	
	4	$26\frac{3}{4}$	1·66	$\frac{1}{6\cdot5}$	$17\frac{1}{2}$	1·09	$\frac{1}{8\cdot5}$	14	·86	$\frac{1}{7\cdot4}$	10	·63	$\frac{1}{161}$	20	
	$4\frac{1}{2}$	$35\frac{1}{2}$	2·21	$\frac{1}{5\cdot1}$	$23\frac{3}{4}$	1·48	$\frac{1}{6\cdot2}$	$18\frac{1}{2}$	1·16	$\frac{1}{7\cdot5}$	$13\frac{1}{4}$	·83	$\frac{1}{190}$	24	
	5	46	2·88	$\frac{1}{4\cdot4}$	$31\frac{1}{2}$	1·96	$\frac{1}{5\cdot4}$	$24\frac{1}{2}$	1·53	$\frac{1}{6\cdot2}$	$17\frac{1}{2}$	1·08	$\frac{1}{216}$	28	
	$5\frac{1}{2}$	58	3·63	$\frac{1}{3\cdot6}$	$40\frac{1}{2}$	2·52	$\frac{1}{4\cdot6}$	31	1·94	$\frac{1}{5\cdot6}$	22	1·38	$\frac{1}{251}$	32	
	6	72	4·5	$\frac{1}{3\cdot2}$	51	3·19	$\frac{1}{4\cdot2}$	39	2·44	$\frac{1}{4\cdot9}$	$27\frac{1}{2}$	1·72	$\frac{1}{325}$	36	
	$6\frac{1}{2}$	..	..	..	$63\frac{1}{2}$	3·96	$\frac{1}{3\cdot9}$	48	3·01	$\frac{1}{4\cdot1}$	34	2·10	$\frac{1}{430}$	40	
	7	..	..	..	78	4·85	$\frac{1}{3\cdot1}$	59	3·66	$\frac{1}{3\cdot4}$	41	2·56	$\frac{1}{544}$	44	
	$7\frac{1}{2}$	..	..	..	94	5·86	$\frac{1}{2\cdot7}$	71	4·40	$\frac{1}{3\cdot6}$	49	3·06	$\frac{1}{658}$	48	
	8	..	..	..	112	7·00	$\frac{1}{2\cdot3}$	84	5·21	$\frac{1}{3\cdot8}$	58	3·62	$\frac{1}{811}$	60	
	$8\frac{1}{2}$	..	..	..	133	8·28	$\frac{1}{2\cdot0}$	99	6·14	$\frac{1}{4\cdot0}$	68	4·25	$\frac{1}{1015}$	70	
	9	..	..	..	156	9·71	$\frac{1}{1\cdot8}$	115	7·18	$\frac{1}{4\cdot2}$	79	4·94	$\frac{1}{1218}$	80	
	$9\frac{1}{2}$	..	..	..	181	11·28	$\frac{1}{1\cdot6}$	133	8·3	$\frac{1}{4\cdot3}$	91	5·69	$\frac{1}{1461}$	90	
	10	..	..	..	209	13·01	$\frac{1}{1\cdot5}$	153	9·54	$\frac{1}{4\cdot5}$	104	6·5	$\frac{1}{1664}$	100	

Ootacamund,
6th July 1880.

(Signed) H. R. MEAD, Major, R.E.,
Superintending Engin

V = charge in Ounces = A (L.L.R.)^2 + B (L.L.R.)^3 for solid rock—For Boulders by Ounces to

ILLUSTRATIONS.



Hole bored in detached to proper depth, i.e., ⅔ Height of Rock.	Vertical Hole bored ⅓ Height of Rock in Depth.	Several vertical Bore holes ⅓ Height of Rock in Depth and 3 feet apart.	Dynamite laid on Rock with no Bore hole and covered with Clay, &c.	Dynamite laid on Rock and exploded without being covered.

EXPLOSIVE CHARGES OF DYNAMITE IN OUNCES AVOIRDUPOIS.

...nce of DYNAMITE to ... Square Feet of Least ...ertical Section.	One Ounce of DYNAMITE to every 2 Square Feet of Least Vertical Section.	One Ounce of DYNAMITE to every Square Foot of Least Vertical Section.	Two Ounces of DYNAMITE to every Square Foot of Least Vertical Section.	Four Ounces of DYNAMITE to every Square Foot of Least Vertical Section.
ozs.	ozs.	ozs.	ozs.	ozs.
..	..	..	..	..
½	1	2	4	8
1	2	4	8	16
2	4	8	16	32
3	6	12	24	48
4	8	16	32	64
5	10	20	40	80
6	12	24	48	96
7	14	28	56	112
8	16	32	64	128
9	18	36	72	144
10	20	40	80	160
11	22	44	88	176
12	24	48	96	192
15	30	60	120	240
17½	35	70	140	280
20	40	80	160	320
22½	45	90	180	360
25	50	100	200	400

(Signed) J. L. L. MORANT, Major, R.E.,
Executive Engineer.

...eer.

GOVERNMENT OF MADRAS.

PUBLIC WORKS DEPARTMENT.

23rd August 1880, No. 1,986 W.

General.
Establishment.

Read the following papers :—

No. 50. No. 187.

One paper on dynamite by Major Morant, with letter.
Two tables,
One plan of experiments with dynamite, } by rail in deal-wood box.
Notes of do. do., }

IN forwarding the very complete and able report on the dynamite experiments lately carried out near Mettupálaiyam, the Superintending Engineer has the honor to make the following remarks :—

2. The experiments may be divided as follows :—

1*st.*—Twenty pieces of selected rock, measuring 36,881 cubic feet or 3,043 tons, were blasted with dynamite.

2*nd.*—Two pieces of selected rock were blasted with gunpowder; they measured 2,589 cubic feet or 211 tons.

3*rd.*—A well was deepened (405 cubic feet of rock being removed) by means of dynamite.

4*th.*—One hundred and ten special experimental blasts were made. Careful record of the above has been kept, and Major Morant in his report has from them laid down certain rules, &c., for carrying on dynamite blasting, which will be most valuable in future work.

5*th.*—With regard to the first and second series of experiments, the work done was what is ordinary blasting for a road or channel, the nature of the rock and its shape, &c., is fully shown in the portfolio of plans, and the results are carefully tabulated in Table I, and again abstracted for dynamite in paragraph 6 of the report.

3. The nature of the rock varied so much it is considered that little or no value can be attached to the cost of blasting different sorts of rock. For example—

Number in Statement.	In Table I, see Plans.	Cost per 100 Cubic Feet.	Nature of Work (see Plans).
		RS. A. P.	
III ...	5	2 8 9	Was a large boulder.
VII ...	18	2 12 9	Very favorable piece.
VIII ...	19	10 3 8	Flat surface removed about 1½ feet in depth.

The last column shows that the kind of the rock had little or nothing to do with the cost.

4. It is considered that the average of the whole is a fair one for ordinary dynamite blasting as regards stores, labor, &c.

For blasting and removing 100 cubic feet the following is required :—

—		Dynamite, lbs.	Gunpowder, lbs.
Dynamite ...	lb.	1	3½
Bore holes ...	Ft. run.	7	16
Fuze	,,	6	13
Detonators ...	No.	3½	...
Men coolies ...	,,	4½	7½

Major Morant considers that the cost of work done with dynamite and gunpowder is as ·7 to 1, or that the dynamite is 30 per cent. cheaper, and to this has to be added the great saving in time that he estimates as one-half.

5. The undersigned considers that the above conclusion is not as favorable to dynamite as might have been drawn from the experiments, but it is sufficient to show that for the future dynamite and not gunpowder should always be used.

6. Nos. 1,037 to 1,069 of notes show the third series, blasts in deepening the well. They are not considered as of much value except that it shows that nearly 8 lbs. of dynamite was used to remove 100 cubic feet. It is believed that if deeper holes had been used in the beginning, the work would have been done cheaper.

7. The fourth series of experiments must be studied in detail; it is from them chiefly that Major Morant has drawn up his table of and rules for dynamite charges in Table II. This table is most complete.

8. Major Morant, in paragraphs 31 to 33, argues that the charge should vary as the square and cube of the line of least resistance, and it is considered that his argument is good. As known formula for charges of blasting materials, however true in theory, can in ordinary practice (owing to different circumstances, such as nature of rock, position, cracks, &c.,) only give approximate charges likely to produce certain effects, it is thought that his table of the charges required is as accurate as can be hoped for or desired.

9. Major Morant has been requested to draw up a short memorandum of instructions regarding the use of dynamite, which, it is hoped, will prove useful to the department.

10. In conclusion the Superintending Engineer considers that great credit is due to Conductor Sub-Engineer Milne for the manner in which he has under Major Morant carried out and recorded the experiments.

COIMBATORE,
26th July 1880.

(Signed) H. R. MEAD, Major, R.E.,
Supg. Engineer, Second Circle.

No. 50-A. *Memorandum by the Chief Engineer, Public Works Department.*

BY G.O., of 24th October 1879, No. 2,686 W., Rs. 1,000 were appropriated for experiments to elucidate the best method of employing dynamite, and to test the economical value of this material as compared with gunpowder for all the ordinary operations of the department.

2. The result is now submitted in the form of a very detailed and valuable report by Major Morant, R.E., sent up under cover of the Superintending Engineer Major Mead's memorandum, No. 187, dated 26th July 1880, and accompanied by a paper on dynamite drawn up apparently for publication in "Indian Engineering."

3. The Superintending Engineer has further requested Major Morant to prepare a short memorandum of instructions regarding the use of dynamite for the use of the department, and it is to be hoped that he may have time to do so before availing himself of his furlough to Europe.

4. The conclusions arrived at by this elaborate series of independent experiments amply confirm the results previously established in other parts of the world, and show very distinctly the decisive superiority of dynamite to gunpowder for all departmental operations. It is not only 30 per cent. cheaper, but, what is even of

greater importance, saves half the time in the execution of work. It may be mentioned that already this material has been extensively used with very satisfactory results in quarrying the stone required for the Madras Harbour Works.

5. When it is considered how tedious are the operations required for blasting out rock on ghât roads, cutting channels through rocky spurs, procuring rough stone for Harbour Works, groynes, and aprons to anicuts, &c., it can hardly be doubted that dynamite should at once displace gunpowder for all such work.

6. Even in the ordinary matter of "getting" metal for road construction and repair, its use will be invaluable from the way in which it shatters the hardest description of rock. In fact, the harder the rock the more decisive are the effects in this respect. This is curiously illustrated by the figures given in paragraph 9 of Major Morant's report, where it is shown that whereas only 56 per cent. of the rock operated on was loosened by gunpowder, no less than 78 per cent. was shattered by dynamite; and again while only 20 per cent. was removable by hand with powder, 62 per cent. was so when broken up by dynamite.

7. The use of this material by Local Fund Boards will in this respect alone save them much of the present outlay on road construction and maintenance.

8. But to the Military Engineer its employment must especially commend itself, and though not as yet provided for in the Sapper and Park Equipments, there can hardly be a doubt that here also it must very soon displace gunpowder, both on the score of its superior dynamic effects, and the safety with which it can be carried and used on field service.

9. Rocks which might easily stop wheeled artillery for days where blasting with powder would have to be resorted to, could with dynamite be got rid of in an hour or two with expert operators. Major Morant's experiments with dynamite laid on rock without any bore hole, sometimes with and sometimes without any covering, are especially instructive in this respect (see his Table II of charges with illustrations).

10. For blowing in the gateway of a fort he shows (paragraph 24) how 5 lbs. of dynamite laid against it in flat bags, so that the thickness of the charge does not exceed 1 inch, would probably shatter the gate from top to bottom.

11. One or two men pushing in front of them a light steel mantlet would thus with comparative safety effect the same results as were attained with large parties, and heavy loss of valuable life experienced in carrying out the demolition of the Cashmere gate at Delhi, and in other similar operations.

12. Even as regards artillery a charge of dynamite if carried in the limber might as a *dernier ressort* be slipped into a gun when compulsorily abandoned, and thus insure its destruction in two minutes, instead of allowing it to fall into the hands of the enemy. See the experiment recorded in Major Morant's paper, where eight ounces of dynamite inserted in a block of wrought iron 120 square inches in section tore it to pieces.

13. These and similar cases will no doubt readily suggest themselves to Engineers and Artillerists, and as the present papers enter so fully into the whole subject, it is only necessary here to add a few words regarding the desirability of early action being taken by Government to remove the very singular prejudice, which, in opposition to all the facts, is entertained against carrying dynamite by some Steamer Companies, and, it is also believed, by some Railways in India.

14. As stated by Major Morant "there are now fourteen dynamite factories in various parts of the world, and since the opening of the first factory in 1866, not a single accident has ever taken place with dynamite, either during carriage or storage. Experience has proved down to present time that the danger of its carriage by rail, ship, or cart becomes absolutely *nil*, so long as the detonators by which it is exploded do not travel with it in the same carriage.

He here no doubt means that the detonators should simply not be in immediate contact, nothing more.

15. All this is abundantly proved by the facts adduced in support. Dynamite may be even blown up by gunpowder, or burnt away slowly like any ordinary substance, without exploding; and the prejudice which at present prevails can therefore only be attributed to complete ignorance of its true nature.

16. It is understood that whereas letter mails may be carried in steamers that have gunpowder on board, they cannot, under existing regulations, be taken where there is dynamite.

17. Only the other day it was of the utmost importance that dynamite should be employed on the works of the Potinghy ghât in Vizagapatam, and yet the British Indian Steam Navigation Company's Steamers refused to carry the 1,000 lbs. of this material which was required. The work has been delayed in consequence.

18. By Government either undertaking themselves the publication of the papers now sent up *in extenso*, or by taking other measures for widely disseminating the information contained in them, the public would be disabused of the very unreasonable prejudice now entertained, and it can hardly be doubted that the department and Engineering profession generally would be much benefited.

19. Major Morant deserves, it is thought, great credit for the very able and intelligent manner in which he has performed the duty entrusted to him, and Conductor Sub-Engineer Milne appears to be fully deserving of the enconiums bestowed upon him by that officer in his report.

OOTACAMUND,
12th August 1880.

(Signed) R. H. SANKEY, Col., R.E.,
Chief Engineer, P.W.D.

No. 51. ORDER THEREON, 23rd August 1880, No. 1,986 W.

THE Government are satisfied from the foregoing report that the object with which the assignment of Rs. 1,000 was made in G.O., of 24th October 1879, No. 2,686 W., has been attained, and has demonstrated the superiority of dynamite as an explosive agent, well adapted for most of the operations, in which gunpowder has hitherto been employed, in the execution of Public Works.

2. This report will be communicated to the Military Department, that the question of employing this material as part of the future equipment of Sapper and Miner Companies and Engineer Field and Siege Parks may be considered.

3. The Judicial Department and the Railway Branch of the Public Works Department will be asked to consider the propriety of allowing dynamite to be carried by steamers and railways with letter mails on the same footing as gunpowder.

4. The thanks of Government are due to Major Morant for his very able and exhaustive report, as also to Conductor Sub-Engineer Milne for the part taken by him in conducting the experiments.

5. A sufficient number of copies of the report* will be printed for use of the Public Works Department and for circulation to the several Governments named in the margin, with fifty added for the general public purposes of Government.

* Without the plans or detail of experiments.

Government of India.
Do. of Bombay.
Do. of Bengal.
Do. of Punjab.
Do. of North-Western Provinces and Oudh.
Chief Commissioner of Central Provinces.
Do. of Burmah.
Do. of Assam.
Do. of Mysore and Coorg.
Governor-General's Agent, Rajpootana.

(True Extract.)

(Signed) R. H. SANKEY, Colonel, R.E.,
Secretary to Govt., P.W.D.

To the Judicial Department.
" Military Department.
" Financial, &c., Departments.
" Consulting Engineer for Railways.
" Chief Engineer for Irrigation.
" Superintending Engineers and Superintendents of Works.

Exd. E. C. Shunker.
Spare Copies

GENERAL.
ESTABLISHMENT.

Govt. of (1880) Madras.

PUBLIC WORKS.

To

THE JUDICIAL DEPARTMENT,

&c., &c., &c.

Dated August, 23rd.

Issued

Recd. Ent.

G. O., 23rd August 1880, No. 1,960 W.

AUGUST.

Nos. 50-51.

Dynamite.—Passing orders on experiments made with — as an explosive agent.

PUBLIC WORKS DEPARTMENT.

No. 7834

Nagpur, 8th December 1880.

FROM

THE SECRETARY TO CHIEF COMMISSIONER,

PUBLIC WORKS DEPARTMENT,

Central Provinces.

To

THE SECRETARY TO GOVERNMENT OF ~~INDIA~~ Madras,

PUBLIC WORKS DEPARTMENT.

SIR,

I am desired to acknowledge the receipt of 7 copies of a report by Major J. Le. Le. Morant R. E. of the results of experiments made to test the value of dynamite as an explosive agent, forwarded with your No 2373 D. of 15th October last, and to solicit that this administration may be supplied with six copies of the "preliminary paper" referred to in para. 4 of the report.—

I have the honor to be,

Sir,

Your Most Obedt. Servt.—

W. Thomson

For Secy. to Chief Commr. C.P.

4-C 4/23 August 1880
15th Oct 1880 No 2278

P.W. Cir No 7850

No. 7834

Nagpur, 8th December 1880

FROM No. 1312

SECRETARY TO CHIEF COMMR.,

PUBLIC WORKS DEPARTMENT,

Central Provinces,

To

SECRETARY TO GOVT. OF INDIA,

PUBLIC WORKS DEPARTMENT.

SUBJECT,

Solicits that this administration may be supplied with six copies of the preliminary paper".

No. 7850

P.W.D.

The paper asked for was ordered "not to be printed".

Instructions are requested as to the reply to be sent to the Chief Commissioner Central Provinces.

R.F.
14.12.80

C & W

Say not printed but if desired a fair copy will be made at the usual rates

14.12.80

Unless there is some reason against

— Military
— Judicial Dept

5-2-81

80

G. C. of 22 August 1885 No 19254
15th Oct 1885 No 23750

S. W. D.

I am not aware, it might perhaps be well to have the paper printed. It is so prominently referred to in Major Morants printed Report that further applications may be expected for copies.

There is no financial objection to charging the Central Provinces Administration for the cost of copying. but we have never hitherto adopted this course. We receive valuable documents, free of charge, from a variety of sources, and return the courtesy when opportunity offers.

R.S.

C.A.W.

15-12

Which will be the probable cost of printing say 100 copies?

15/12

S. W. D.

Military
Judicial Dept

5-2-01

Pol. Regulations 19 Nov
15th Octr 1880 No 2375 W

The cost of printing 100 copies would be about Rs 60 to Rs 70.
R.S.
15-12

Sanctioned
Octt
15/12/80

P. W. D.

No 324 W dt 5 Feby 1881

To,
The _____

Sir,

I am directed to forward for information _____ copies of the Paper on Alfred Nobel's Dynamite by Major Morant R.E referred to in para: 4 of his letter recorded with G.O. 1986 W dated 23rd August 1880.

To,
The Secy: to the Govt. of India.
_____ do _____ of Bombay
_____ do _____ of Bengal
_____ do _____ of Punjab
_____ do _____ of N.W.P. & Oudh.
_____ do _____ to the Chief Commr. of C.P.
_____ do _____ do _____ of Burma
_____ do _____ do _____ of Assam.
_____ do _____ do _____ Mysore & Coorg
_____ Governor Genl's Agent Rajpootana.
_____ Supt. Engrs. & SWS of Works.
_____ Chief Engr. for S.
_____ Consg. Engr. for Rajp:
_____ Financial Dept.
_____ Military Dept.
_____ Judicial Dept.

R.S.

Recd
5-2-81

P.W. Dept

One hundred copies of the "Paper on Alfred Nobel's Dynamite by Major Morant RE." having been printed, the following distribution will be made:

The Secy to the Govt of India	6	copies
" " of Bombay	6	"
" " of Bengal	6	"
" " of Punjab	6	"
" " of N.W. Provinces & Oudh	6	"
" Chief Comr of Central Provinces	6	"
" " of Burmah	6	"
" " of Assam	6	"
" " of Mysore & Coorg	6	"
Governor General's Agent, Rajputana	6	"
Supt of Engineers & Deputs of Work	7	"
Chief Engineer for Irrigation	2	"
Consulting Engineer for Railways	5	"
Financial Department	5	"
Military Do	5	"
Judicial Do	5	"
In store	11	"
Total	100	Copies

R.S. 31-1-81

S 1/2