

The ash consisted of—

Silica,	57.93
Titanic acid,	0.80
Alumina,	22.74
Peroxide of iron,	8.71 = Metallic iron, 6.10 per cent.
Lime,	6.04
Magnesia,	1.29
Potash,	0.94
Phosphoric acid,	0.06
Sulphuric acid,	0.51
	<hr/>
	99.02
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The above analysis of Warora coal corresponds with those given of this and of other coals of the district in the Memoir by Mr. T. W. H. Hughes on the Wardha Valley Coalfield, pages 99 to 103, (Memoirs of the Geological Survey of India, Vol. XIII., Part 1).

The sulphur contained in the coal is present chiefly in the form of pyrites, which occurs in part in large pieces that may be picked out, in part in nests, and in part spangles the surface of occasional blocks of coal.

In an experiment made to test the extent to which it would be possible to remove the sulphur, by washing, a sample of coal, in coarse powder, which contained by analysis 1.137 per cent. of sulphur, was washed, with the result that the washed coal contained 0.86 per cent. of sulphur, and the residue 5.23 per cent. By powdering the coal more finely, and by classifying and washing it with care, a larger proportion of the sulphur that it contains may no doubt be removed, but it is very questionable whether the whole or nearly the whole can be got out by any practicable process.

The relatively small amount of fixed carbon that is contained in these coals, and the large percentage of water that they retain, even after they have been stored under cover for months, indicate that they are more closely allied to lignites than to ordinary coals; and this view is confirmed by their behaviour when coked, and by the ultimate analysis given of one of the varieties of Sásti coal, on pages 102 and 103 of Mr. Hughes's Memoir.

Lignite dried in the air retains generally 15 to 20 per cent. of water, or more, which may be driven off by exposure to a temperature of 212°

Fahr. Warora coal that had been stored under cover, in London, for more than a year retained, by Mr. Riley's analysis, 11 per cent.

Dr. Percy gives the following as the relative composition of wood and peat, of dry lignite, and of coal; the proportion of carbon being taken in each case as equal to 100 (Metallurgy, French edition, 1864, Vol. I., page 127).

	Carbon	Hydrogen	Oxygen	Hydrogen in excess
Wood (mean of 26 analyses), ..	100	12.18	83.07	1.80
Peat,	100	9.85	55.67	2.89
Lignite (average of 15 varieties), ..	100	8.37	42.42	3.07
10-yard coal (South Staffordshire),	100	6.12	21.23	3.47
Tyne steam coal,	100	5.91	18.32	3.62
South Wales coal (Pentrefelin col- liery),	100	4.75	5.28	4.09

The "hydrogen in excess" is that available as a source of heat; that is, the quantity in excess of the amount required to form water with the oxygen present.

The composition of the Sásti coal is as follows:—

	Carbon	Hydrogen	Oxygen and Nitrogen
A. Shaft, good coal (average), ..	63.61	3.40	20.98
B. „ (best samples), ..	74.07	4.90	9.92
C. „	74.83	4.60	12.15

Taking the proportion of carbon as equal to 100, as in the table above, this is equivalent to—

	Carbon	Hydrogen	Oxygen and Nitrogen	Hydrogen in excess
A. Shaft,	100	5.35	82.98	1.23
B. „	100	6.61	13.39	4.94
C. „	100	6.19	16.35	4.15

In estimating the proportion of hydrogen in excess, the nitrogen contained in the coal is calculated as oxygen, but as the amount of this, in coals and lignites, rarely exceeds 2 per cent., the error is unimportant.

Comparing the compositions of the three varieties of Sásti coal with those of different fuels, as given above, it will be seen that while the coals from the B and C shafts contain an exceptionally large amount of hydrogen, in excess of that required to form water with the oxygen present, and are thus fuels of considerable heating power, and resemble in composition the true coals of Europe; that obtained from the A shaft, which, from its lower percentage of carbon, is probably more similar in character to Warora coal, contains even less available hydrogen than is commonly found in wood.

The solidity and hardness of the coal are little, if at all, affected by drying it, so as to expel the contained water, but when it is heated to redness, in a close vessel, to drive off the volatile portions, it decrepitates to a considerable extent, and does not cake in the least; nor does it swell up like South Staffordshire non-caking coal, but shrinks together, as wood and lignite do when charred, and the coke left, consisting of the fixed carbon and the ash, is small in quantity (57·36 per cent. from the undried coal, according to Mr. Riley's analysis), much broken up, friable, and somewhat similar in appearance to wood charcoal. It weighs, in bulk, about 35 lbs. per cubic foot.

A lump of the coal, about a pound in weight, imbedded in sand, in a large crucible, and coked slowly for several hours, was found on turning it out, when cold, to be split to pieces.

Trials were made, without success, to produce a hard coke from the coal, by coking mixtures of it, in powder, with different proportions of caking coal and of pitch. The caking coal used was from Llyndu colliery, near Bridgend.

The following are the particulars of the experiments:—

No	Warora Coal	Caking Coal	Pitch	Results
1	.. 100	..	5	.. Did not coke.
2	.. 100	..	5	.. (Moistened and pressed). Did not coke.
3	.. 100	..	10	.. Did not coke.
4	.. 100	..	20	.. Did not coke.
5	.. 100	..	30	.. Coked slightly.
6	.. 100	..	40	.. Better than No. 5, but when pressed with the fingers, it crumbled to powder.
7	.. 100	30	..	.. Coked slightly.
8	.. 100	40	..	.. Better than No. 7.
9	.. 100	50	..	.. Tolerable coke, but not fit to bear a great weight in a blast furnace.

The iron ores from the Chánda district, sent by the steam ship "Burmese" to be tested in England, are from Lohara and Pipulgaon. The following are Mr. Riley's analyses:—

	Lohara	Pipulgaon
Silica,	0.51	12.59
Peroxide of iron,	88.85	71.84
Protoxide of iron,	8.12	10.24
Oxide of manganese,	0.27	Trace.
Alumina,	0.94	3.08
Lime,	Nil.	Trace.
Magnesia,	0.55	0.28
Phosphoric acid,	0.04	Nil.
Sulphur,	Nil.	Trace.
Combined water,	0.88	2.12
Moisture,	0.19	0.20
Copper,	Nil.	Nil.
Titanic acid,	Nil.	Nil.
	<u>100.30</u>	<u>100.30</u>
Metallic iron, per cent.,	68.52	58.25

In each case, the sample for analysis was taken from a lot of 4 cwt. of the ore, of average quality, crushed and mixed.

The ores are hard and compact mixtures of peroxide of iron with some magnetic oxide, and are exceptionally free from deleterious impurities; but from their hardness and compact texture they are reduced with difficulty, and will require more fuel, if smelted in a blast furnace, than if they were porous and readily reduced, as the gas passing through the furnace must contain a larger proportion of carbonic oxide. In reducing the ore, with coal and with charcoal, in closed crucibles, I found that it was acted on with comparative slowness, and Mr. Ireland mentions in a letter to me, that whereas ordinary Lancashire hæmatite is reduced to spongy iron in the Blair furnace in six hours, the Lohara and Pipulgaon ores took 10 hours.

The late Mr. David Forbes gives the following analyses of samples of ores from the same neighbourhood, examined by him some years ago for Major Lucie Smith. (Journal of the Iron and Steel Institute, 1872, page 133).

	Lohara	Dewulgaon	Goonjwal
Iron, metallic,	69.208	70.006	70.134
Oxygen in combination,	29.876	28.670	28.789
Sesquioxide of manganese,	0.090	0.084	0.108
Silica,	0.823	0.813	0.545
Alumina,	0.432	0.387	0.396
Lime,	0.054	0.026	0.055
Magnesia,	Trace.	Trace.	Trace.
Sulphur,	0.012	0.013	0.020
Phosphorus,	0.005	0.001	0.003
	<u>100.000</u>	<u>100.000</u>	<u>100.000</u>

According to these analyses, the specimens of ore examined contained more magnetic oxide than the samples analyzed by Mr. Riley; and Mr. Forbes remarks that they were all "compact admixtures of the native magnetic oxide of iron, with more or less specular oxide, (or crystallised hæmatite,) and equal in quality to the finest Swedish iron ores, so that there can be no question as to their suitability for producing the very finest iron or steel, when smelted with charcoal or with coke, provided the coal of the Chánda basin is of sufficiently good quality."

The limestone sent to England with the coal and ore is a dark grey, hard, compact stone, and contains, by Mr. Riley's analysis of an average sample—

Silica,	15.75	
Alumina,	3.52	
Protoxide of iron,	1.79	
Peroxide of iron,	Traces.	
Oxide of manganese,	0.15	
Lime,	48.17	equivalent to 77.08 per cent of
Magnesia,	0.80	carbonate of lime.
Carbonic acid,	33.20	
Phosphoric acid,	0.09	
Sulphuric acid,	0.08	
Combined water,	0.91	
Moisture,	0.26	
	<u>99.72</u>	

This is not at all a rich limestone, and contains rather more phosphoric acid than is desirable in stone to be used as a flux for such high class ores as those of the Chánda district; but it is probable that stone richer in lime, and containing at the same time less phosphoric acid, may be found in the neighbourhood; as, according to Mr. Hughes (page 112), Vindhyan limestone, which is of good quality and uniform in composition, occurs within six miles of Warora, near the line of the proposed railway from Hinganghat. This contains—

Carbonates of lime and magnesia,	96.8
Alumina and oxide of iron,	1.2
Phosphoric acid,	Trace.
Insoluble,	2.0
	<u>100.0</u>

Mr. Ness writes, in a letter to you, dated the 25th September 1878, that rich manganese ore has been found, in any quantity, and with an outcrop 10 feet thick, at Munsir, about 12 miles north by east of Kamptee, and Mr. Riley's analysis of a sample of it is as follows:—

Silica,	7.75	
Peroxide of manganese,	48.42	} = Metallic manganese, 56.02 per cent.
Protoxide of manganese,	32.80	
Peroxide of iron,	6.60	= Metallic iron, 4.62 per cent.
Alumina,	0.58	
Baryta,	0.59	
Lime,	Trace.	
Magnesia,	0.48	
Phosphoric acid,	0.13	
Oxides of nickel and cobalt, ..	0.80	
Combined water,	1.50	
Moisture,	0.58	
	99.73	

II.—Blast Furnace Experiments at Warora.

Two attempts to smelt the Chánda iron ores with Warora coal, in a blast furnace, were made by Mr. Ness, at Warora, in August and September 1875.

The furnace used was 24 feet high, 2 feet in diameter at the bottom of the hearth, 2 feet 6 inches at the top of the hearth, 6 feet 6 inches at the top of the boshes, and 3 feet 10 inches at the throat, and the hearth was 3 feet 3 inches deep. Its capacity was thus 426 cubic feet.

It was blown with three tuyeres, 2½ inches in diameter at the nozzle, and the blast was warmed to the temperature of 150° Fahr. The air at the time of the experiment was saturated with moisture, the monsoon not being over.—(Hughes, *op. cit.*, page 143.)

The ores employed were Lohara ore, already described, and brown ore from Ratnápúr, containing (page 111) about 50 per cent. of metal and 25 per cent. of earthy matter, insoluble in acids.

In both cases the experiments were conducted in the same manner; but on the first occasion the giving way of one of the tuyeres, two days after the furnace had been lighted, allowed water to get into the hearth, and cooled this to such an extent that the experiment had to be stopped.

Mr. Ness thus describes the second trial, in a report dated 12th October 1875, (Public Works Department Proceedings for May 1876):—

"The furnace, after being thoroughly dried, was filled for about three-fourths of its capacity with rough dry timber, and set fire to; on the top of this a few feet of charcoal was placed, and then regular charges of iron ore and coal, &c., were made, consisting of 1 cwt. coal to $\frac{1}{4}$ cwt. of Lohara iron ore, $\frac{1}{4}$ cwt. Ratnápúr iron ore, 20 lbs. limestone, and an occasional blank charge of coal or charcoal, this course being continued till the furnace was full; in 24 hours after lighting the furnace, the molten slag began to come down into the hearth, then blast was let on quietly, and in three hours thereafter the slag made its appearance at the cinder notch. The pressure was increased to about $1\frac{1}{2}$ lbs. per square inch on the second day. During this time the slag formed and came off in larger quantities, and the hearth quickly filled with spongy iron, which would not liquify. Seeing this, I increased the blast, and added more blank charges of coal, and kept on increasing the temperature of the hearth, till I fused the firebricks, the tymp plate, and even the bottom of the hearth, still, the iron that had settled down was so mixed with the ashes of the coal that it would not liquify, and only kept accumulating, till the iron reached the top of the tuyeres, and then a stop was put to all further proceedings, till the mass was dug out, which is over a ton in weight."

In another account of the experiment, in a letter to the South Staffordshire Mill and Forge Managers' Association, Mr. Ness gives the weight of the mass of malleable iron that gathered in the hearth of the furnace as over 30 cwt., and states that towards the end of the trial the pressure of blast was increased to a little over 3 lbs. to the square inch, and its volume to about 500 cubic feet per minute.—(Hughes, page 143).

Further on, in the report above quoted (paragraph 5), Mr. Ness comments on the result of the experiment as follows:—

"My reason for taking the course I have just described being, generally, that in the aggregate the amount of foreign matter in many of the mixtures used in blast furnaces at home is not much less than is found in the mixture I expected to succeed with here; for example, it is not unusual, in England and elsewhere, to find 5 per cent. of ash in the coal and 15 per cent. of silicates in the iron ores; when the quantities required of these two to make a ton of iron are taken, we have a total of 10 per cent. from coal + $22\frac{1}{2}$ from iron ore, total $32\frac{1}{2}$ per cent., whereas at Warora we have 30 per cent. from the coal, and about 5 per cent. from the iron ore, or a total of 35 per cent. of foreign matter, besides

what is found in the limestone used for a flux, which is similar in quantity in both cases. This excess of $2\frac{1}{2}$ per cent. I fully expected to be overcome by part of the ash in the coal acting as a flux, but in practice it has not, and what has added much to the non-success of the experiment is the tendency the coal has, on entering the furnace, to decrepitate, and when it reaches the neighbourhood of the tuyeres, impoverished, to retain part of its fixed carbon, and in this semi-carbonized state is imbedded amongst the iron in the hearth, although there is evidence of an excessive heat in the hearth, from the firebricks (which are of the best quality) being melted for 6 inches in the thickness of the lining."

It is quite true, as Mr. Ness states, that in many of the mixtures commonly worked in blast furnaces, the proportion of earthy matter to the metallic iron contained in the charge is as great as in the mixture he used here; indeed, it is often much greater.

Thus, in the charge tried at Warora, the amounts of slag-forming materials and of iron are approximately as follows:—

	Quantity charged	Slag-forming materials	Iron
	Cwt.	Cwt.	Cwt.
From the coal,	1.00	0.189	0.008
From the Lohara iron ore, ..	0.25	0.008	0.171
From the Ratnápúr iron ore, ..	0.25	0.063	0.125
From the limestone,	0.178	0.116	..
Totals,	..	0.326	0.304

Or, assuming that 0.304 cwt. of iron, contained by analysis in the charge, would correspond, in practice, to about 0.316 cwt. of pig iron, the amount of slag produced for 1 cwt. of pig would be about 1.08 cwt.

In the blast furnaces of the Cleveland district, the average amount of slag produced is about 1.5 to 1.6 cwt. of pig iron made.

The proportion of slag-forming materials contained in the charge has, however, comparatively little effect on the working of a blast furnace; but, in the case of the Warora experiment, several other conditions were present, which fully account for the failure to produce pig iron, whatever were the characters of the coal and ore used.

It was a mistake, in the first place, to attempt to smelt altogether with raw coal, without an admixture of coke or charcoal, in using cold or nearly cold blast; for damp air, heated to only 150° Fahr. was practically

equivalent to cold blast. In England and Scotland the use of raw coal has been found to be practicable only since hot blast, heated to from 300° to 800° Fahr. or more, has been used. At the Clyde Iron Works, for instance, before 1830, when using cold blast, coke only was employed in the blast furnaces, and in South Staffordshire and many other districts, even with the help of hot blast, and in working with a coal that does not contain nearly so much volatile matter as undried Warora coal, raw coal is not used without an admixture of coke; as, if employed alone, it would cool the furnace too much.

Thus, in Staffordshire, in one instance, in 1871, the proportions used per ton of pig iron produced were—

									Cwt.
Coal,	..	..	..	..	..	..	..	..	35.87
Coke,	..	..	..	..	..	..	..	..	11.40
									<hr/> 47.27 <hr/>

and in Austria and Italy, where lignite is used in several places, in blast furnaces, it is always employed in admixture with wood charcoal.

The furnace tried at Warora was also much too low, only 24 feet high. I do not know that a blast furnace so low as this is in successful work anywhere, even for smelting porous and readily reduced ores with wood charcoal. Charcoal blast furnaces, as now constructed, vary from 26 up to 50 or 55 feet in height, and furnaces in which hard coke is the fuel used are much higher, particularly when the ore also is hard, and is reduced with comparative difficulty. Where this is the case, as in Cleveland, the blast furnaces employed are generally from 70 to 80 feet high, and furnaces varying from 90 to 100 or 105 feet in height are not uncommon. The increase of height, up to a limit of between 70 and 80 feet, is found to be attended by a marked saving in fuel.

This great height is needed to admit of the complete reduction of the ore by the ascending current of gases, and the carburizing of the reduced metal before it reaches the zone of fusion near the tuyeres; to enable the gases, as they ascend, to act on the ore as fully as possible, so that, when they pass off, they may contain the greatest possible proportion of carbonic acid; and to cool them, by contact with the materials charged.

When charcoal or soft coke is the fuel used, or when the ores smelted are friable, the practicable height of the furnace is limited by the strength of the charge to resist crushing; and in the case of charcoal furnaces,

especially, the diameter is often kept small (between one-fifth and one-sixth only of the height), in many cases because a larger furnace is not needed, but also to ensure a more uniform distribution of the ascending gaseous current through the charge, and to partly support this, by friction against the sides, so as to admit of making the furnace high enough to ensure economical working, without bringing too great a crushing pressure upon the lower part of its contents.

When raw non-caking coal is used, great height in the furnace is even more advantageous than in other cases, as the ascending current of gas has not only to reduce the ore and to heat the charge, but also to drive off the volatile portion of the coal. The softness of the coke of such coal limits, however, the height of the furnaces, as they are ordinarily constructed, to between 50 and 60 feet; though Mr. Ferrie, of the Monkland Iron Works, near Glasgow, has lately succeeded in working, with raw coal, a furnace 83 feet high, by building it with the upper part divided by vertical cross walls into four sections, by friction against the sides of which the charge is partly supported, and is thus kept from crushing together too heavily.

By this alteration, aided to some extent by the heating of the upper part of the charge, by means of flues in the cross walls and in the corresponding part of the ring wall, the consumption of coal, per ton of pig iron, has been reduced from 51 cwt., the rate in ordinary Lanarkshire furnaces, 52 feet high, to about 34 cwt. This is an equal saving in fuel to that effected in the Cleveland blast furnaces, smelting Cleveland iron ore with Durham coke, by increasing the height from 48 feet to 75 or 80 feet. In this case, the effect of the increased height has been to reduce the consumption of coke, per ton of pig made, from 30 cwt. to about 22 cwt.

I am not aware that, even with the aid of hot blast, pig iron is made anywhere with raw coal as fuel, in furnaces less than 40 feet high, and it is I think questionable whether it could be made, with even the best South Staffordshire or Scotch coal, in a furnace only 24 feet high.

A third cause of failure was that the proportion of coal used was too small.

The only portion of the fuel that is of any use in a blast furnace is the fixed carbon, as the volatile part is carried away unburned in the ascending current of gases, and while it enriches these, and increases their

heating power when burned outside the furnace, with a further supply of air, it only cools this, by the heat absorbed in driving it off.

In the trial at Warora, 1 cwt. of coal, containing only 0.434 cwt. of fixed carbon, was used with each charge of $\frac{1}{2}$ cwt. of ore, which would yield, under suitable conditions, as above estimated, 0.316 cwt. of pig iron. This would be equal to about 27.5 cwt. of fixed carbon, in the fuel, per ton of pig, a much smaller proportion than pig iron was ever made with, in using coke and cold blast, except in furnaces 60 or 70 feet high, an absurdly small amount for so low a furnace, and actually less than is now used in smelting with raw coal, even with blast heated to about 800° Fahr., and in furnaces more than 50 feet high.

At the Clyde Iron Works, when working with cold blast, the coke from $8\frac{1}{4}$ tons of coal, or about four tons of fixed carbon, was the quantity used per ton of pig iron made; in modern Lanarkshire furnaces, employing hot blast, 51 cwt. of coal, containing about 60 per cent. of fixed carbon or over 30 cwt. of carbon, is the proportion per ton of pig; and in South Staffordshire the amount used, in good modern practice, with hot blast, and in a furnace 54 feet high, was in one case, as already mentioned, 35.9 cwt. of coal and 11.4 cwt. of coke per ton of pig, or together more than 32 cwt. of fixed carbon.

In the height of the furnace employed, and the whole conduct of the experiment, the attempt to smelt the Chánda ores that was made at Warora resembled rather the mode of working formerly in use in the German stückofen and the Swedish Osmund furnace, before the blast furnace, as it is now known, had been invented.

These furnaces were from 10 to 16 feet in height, and were worked with charcoal and cold blast. After lighting the fire and partly filling the furnace with charcoal, alternate charges of fuel and ore were put in, and the blast kept on until the reduced metal had accumulated to a sufficient extent, as a malleable mass, in the hearth. The blast was then shut off, part of the furnace breast taken down, and the lump of metal removed and hammered into blooms or bars.

When the furnace was made higher, or more charcoal was used in proportion to the ore, the reduced metal was more or less carburetted, or sometimes liquid cast-iron gathered in the hearth, instead of a malleable ball.

As charcoal was the fuel used in the stückofen, the bloom of reduced

iron obtained was not mixed with much ash, and could be forged at once into merchantable bars. Where coal or coke is the fuel with which the furnace is worked, this is not practicable, as the earthy ash that these leave, when burned, remains mixed with the iron, and keeps it from sticking together. In this case, a successful result is to be attained only by conducting the process in such a way as to produce liquid cast-iron and a liquid cinder, instead of a ball of solid metal, mixed with part of the ash left from the fuel.

In a modern blast furnace, the aim is always to obtain liquid cast-iron, instead of malleable metal, in the hearth, and with this object the furnace is made much higher than the stückofen, and care is taken, in working it, to keep the product of the required character, by reducing the proportion of ore if a sufficiently carburated liquid product is not obtained.

Thus, in lighting a blast furnace, the practice is to put in comparatively little ore, in proportion to the fuel charged, until the furnace is fully hot, and pig iron of the required character has appeared at the hearth, and then to increase gradually the ratio of ore to fuel, as the furnace is found to bear it, until the maximum proportion is reached that will yield metal of the required quality.

The same watchfulness is required, so long as the furnace is at work, to keep it on a uniform quality of product; the proportion of ore to fuel, and the "rate of driving," that is the amount of blast supplied, being increased or diminished from day to day, according as the furnace, from changes in the weather or from other accidental causes, is found to be working better or worse and producing more or less grey metal.

When a blast furnace is driven too fast, so that the ore comes too quickly down into the hearth, before it has been sufficiently reduced and carburated, the quality of the metal at once falls off, and either the rate of driving must be reduced or a larger proportion of fuel must be charged. The rate of driving that a furnace will bear is known only by trial.

This tentative mode of working, though always adopted in regular blast furnace management, is especially necessary where, as at Warora, all the conditions are strange, and it is difficult to predict what proportion of fuel to ore will be required.

If the furnace at Warora had been started with 4 or 5 cwt. of coal to each charge of $\frac{1}{2}$ cwt. of ore, though it is questionable whether pig iron of any value would have been obtained in so low a furnace, with cold

blast, and in using raw coal, yet the result would have been better than it was, and liquid white cast-iron, instead of a malleable ball, might very probable have been obtained.

The attempt made to melt down the mass of metal, in the hearth of the furnace, after it had collected there, necessarily failed, as malleable iron is in itself almost infusible, the cast-iron that it was sought to obtain being a fusible carburet of the metal, containing 2 to 4 per cent. of carbon and some silicon, and not the metal itself. Since the flame near the tuyeres is more or less oxidizing, its action would be rather to burn out from the metal any carbon that it might contain than to put more in.

In the normal working of a blast furnace, the carburization of the reduced iron takes place at some distance above the tuyeres, and the only action close to them is the combustion of the remaining carbon of the fuel and the melting of the already carburetted metal and of the materials forming the slag.

As the experiment at Warora was so conducted that a successful result could not have been obtained from it, whatever qualities of coal and ore had been used, its failure is not to be regarded as a proof that the production of pig iron from the minerals of the Wardha Valley is impracticable. Indeed, so far as the trial went, though it was economically a failure, its results, when analyzed, are very encouraging.

It showed that the coal, though it decrepitates when thrown into a blast furnace, does not do so to such an extent as to check the passage of the blast; that up a height of stack of 24 feet, at least, the coke in the lower part supports the weight of the mass above it very well, and does not become so crushed together as to check the blast; that sufficient fixed carbon remains in the fuel, when it comes down to the tuyeres, to produce an intense heat in the hearth; and that in a height of 24 feet only, at the rate of working adopted, the ore is thoroughly reduced and the greater part of the work of making it into pig iron is done.

III.—*Working of the Minerals in a Blast Furnace.*

The difficulty in the way of working the Chánda ores with Warora coal in a blast furnace is not that the coal contains only a small percentage of fixed carbon, in proportion to the volatile matter, together with a large amount of ash; if this were all, it would necessitate merely the use of more coal in proportion to the ore charged, or the use of coked coal, or of a mixture of coked and raw, instead of all raw coal. Nor is

it that the ores are dense and difficult of reduction; they are not more dense than the well known magnetic ores of Sweden, which are smelted readily, and the trial made at Warcra showed that they could be reduced to spongy metal with moderate ease.

The real difficulty, a difficulty that may possibly prove an insuperable bar to the practical working of a blast furnace with this coal, is that the coke which it yields is soft and friable, so friable that it may be broken to pieces with the fingers, and that, though it worked well in the experimental furnace, it would crush to such an extent in a blast furnace of the size and form of those in which raw coal is commonly used, as to prevent the passage of the blast.

The trials made to produce coke from mixtures of crushed Warora coal with caking coal or with pitch, show also that a good blast furnace fuel cannot be made from it, practically, in this way.

I have endeavoured to determine, approximately, the relative resistance to crushing of the coke from South Staffordshire non-caking blast furnace coal, of the coke from Warora coal, and of wood charcoal, as affording some indication of the greatest dimensions of the blast furnace in which it would be advisable to attempt to use the coal.

The Staffordshire coal was kindly supplied by Messrs. Cochrane & Co., Woodside Iron Works, near Dudley, and is a sample of what they use regularly in their furnaces. These are 54 feet 6 inches high by 15 feet diameter of bosh; and, from the working of the coal in them, Messrs. Cochrane & Co. consider that it might be used, without difficulty, in furnaces 60 feet high.

As field-burned charcoal could not be readily obtained, that made in retorts, and used in South Wales in making "charcoal" tin-plate bars, was employed instead, but before being used in the experiments it was again heated to redness, in closed crucibles, in order to ensure that it was thoroughly charred, and to drive off any water that it might have absorbed. It was allowed to cool in the crucibles, and was turned out when cold.

The coal was in pieces that would go through a screen with meshes $2\frac{1}{2}$ inches square, but not through one with meshes 2 inches square. It was thoroughly dried before weighing, and was coked in crucibles, in two cases at a low heat, and in two at a high heat.

The comparative resistance to crushing of each sample of coke and charcoal was tested by putting it, together with a heavy ball, into a hol-

low drum fixed on a horizontal axis, giving it in each case 50 turns, and noting to what extent it was crushed.

The whole contents of each crucible were put together into the drum, so that the proportion of small contained in the coke, after crushing, included that due to the decrepitation of the coal when coked. The drum was 24 inches in diameter by 6 inches wide, inside, and the ball used for crushing was a round stone not quite 3 lbs. in weight. Each sample was crushed at a uniform speed of 10 turns per minute, and it was then classified, by sifting it successively through sieves of 2, 1, $\frac{1}{2}$, $\frac{1}{4}$ and $\frac{1}{8}$ inch mesh, and the part retained by each sieve was weighed.

The following are the results of the experiments:—

Warora Coal.

	Coked at Low Heat		Coked at High Heat	
	Grains	Per cent.	Grains	Per cent.
Weight charged into crucible, ..	85,000		85,000	
Weight out,	22,410		23,450	
Weights retained (after crushing)—				
By 2-in. sieve,	None.		None.	
" 1 "	2,000	13.5	5,510	23.6
" $\frac{1}{2}$ "	10,820	48.6	8,750	37.5
" $\frac{1}{4}$ "	8,580	16.1	4,060	17.4
" $\frac{1}{8}$ "	1,620	7.2	1,500	6.4
Fine,	3,250	14.6	3,530	15.1
	22,270	100.0	23,350	100.0
Loss,	140		100	
	22,410		23,450	

Staffordshire Coal.

	Coked at Low Heat		Coked at High Heat	
	Grains	Per cent.	Grains	Per cent.
Weight charged into crucible, ..	85,000		85,000	
Weight out,	22,350		21,690	
Weights retained (after crushing)—				
By 2-in sieve,	820	3.8	None.	
" 1 "	4,350	19.7	1,230	5.7
" $\frac{1}{2}$ "	12,290	55.8	14,760	68.6
" $\frac{1}{4}$ "	1,880	6.8	2,490	11.6
" $\frac{1}{8}$ "	1,080	4.9	850	3.9
Fine,	2,100	9.5	2,190	10.2
	22,020	100.0	21,520	100.0
Loss,	330		170	
	22,350		21,690	

Wood Charcoal.

	Heated to Low Heat		Heated to High Heat	
	Grains		Grains	
Weight charged into crucible, ..	10,500		10,500	
Weight out,	7,470		7,460	
<hr/>				
Weights retained (after crushing)—		Per cent.		Per cent.
By 2-in. sieve,	None.	..	None.	..
" 1 "	1,200	15.6	1,360	18.4
" $\frac{1}{2}$ "	4,500	58.3	3,860	52.1
" $\frac{1}{4}$ "	1,170	15.2	1,450	19.6
" $\frac{1}{8}$ "	260	3.4	230	3.1
Fine,	580	7.5	500	6.8
	7,710	100.0	7,400	100.0
<hr/>				
Error (excess).. ..	240		Loss 60	
	7,470		7,460	

The sums of the percentages of each fuel that were retained, after crushing, by the 2-inch, 1-inch, and $\frac{1}{2}$ -inch sieves, taken together, are :—

	Low Heat	High Heat	Mean
Warora coke,	62.1	61.1	61.6
South Staffordshire coke,	79.3	74.3	76.8
Wood charcoal,	73.9	70.5	72.2

If the percentage of each fuel that was retained by the $\frac{1}{4}$ -inch sieve is included in the calculation, the charcoal takes a still higher position, but Warora coke remains the most friable of the three.

Thus, the sums of the percentages of the fuels that were retained by the 2-inch, 1-inch, $\frac{1}{2}$ -inch, and $\frac{1}{4}$ -inch sieves, taken together, are as follow :—

	Low Heat	High Heat	Mean
Warora coke,	78.2	73.5	75.85
South Staffordshire coke,	85.6	85.9	85.75
Wood charcoal,	89.1	90.1	89.6

The coke from South Staffordshire coal and wood charcoal are thus much on an equality, in their resistance to crushing, as tested in the revolving drum. The coke made, on the one hand, a larger percentage of fine, that would pass through a $\frac{1}{2}$ -inch sieve, than the charcoal; 9.85 per cent., on the average, against 7.15 per cent.; but it yielded, on the other, a greater proportion of pieces of the larger sizes.

The greater percentage of large that the coke yields, when crushed by

an equal weight, gives it an advantage in the blast furnace; and if they were of the same density it would admit of the furnaces being higher for South Staffordshire coal than for charcoal.

The greater lightness, however, of charcoal than of coke renders the pressure of a column of mixed charcoal and ore less than that of an equally high column of coke and ore, and to a great extent redresses the inequality; so that, in practice, coal furnaces and charcoal furnaces work well when of nearly equal maximum height.

Blast furnaces, working coal, are generally 50 to 55 feet high by 12 to 15 feet in diameter of bosh, and the largest charcoal furnaces are of equal height, and about 10 feet in diameter at the boshes.

A furnace using Warora coal, and more than 25 or 30 feet high, would probably choke up, from the crushing together of the fuel, if it were made as wide as coal furnaces generally are; and since 40 feet is about the least height of a furnace that will work satisfactorily, burning coke or coal, the ordinary Scotch or Staffordshire form of furnace cannot be used.

A furnace similar to that built by Mr. Ferrie, and already referred to, may, however, be found suitable, and it is in this direction that any further blast furnace experiments with Warora coal should be made.

Mr. Ferrie, using the same coal and ore as those ordinarily smelted, in the Glasgow district, in furnaces 52 feet high and 15 to 18 feet in diameter at the boshes, and that cannot be worked in higher furnaces, of the common form, on account of the crushing of the charge, has succeeded in smelting in a furnace 83 feet high, by dividing 30 feet of the upper part of the shaft, by vertical cross walls, into four sections, by friction against the sides of which the weight of the charge is partly supported. Mr. Ferrie makes flues, also, in these cross walls and in the corresponding outside walls of the furnace, in which part of the escaping gas is burned; and by the two arrangements jointly, the saving effected amounts to 19 cwt. of coal per ton of pig iron made.—(I. L. Bell, *Chemical Phenomena of Iron Smelting*, page 309.) I send with this a copy of the *Journal of the Iron and Steel Institute*, for May 1871, in which Mr. Ferrie's furnace is described.

Ferrie's furnace seems to have been introduced more successfully in the United States of America than at home. At the works of the Etna Iron Company, at Ironton, Ohio, U. S. A., there are two of these

furnaces, 87 feet 6 inches high, working with blast heated in Whitwell's firebrick hot blast stoves. An account of the blowing in of the first furnace is contained in "Iron" for 1st April 1876, page 427, and notices of their working are given in the Foreign Reports to the Iron and Steel Institute, No. 1, 1876, page 247, and No. 2, 1877, page 7.

They appear to work well, but according to the late Mr. Whitwell (Journal of the Iron and Steel Institute, 1878, page 208), the coal used is found to be too soft to stand the crushing action of so high a column of materials, and a small proportion of coke is used with it, to keep the furnace open. In Staffordshire, as Mr. Whitwell states (*loc. cit.*) a furnace of this type is also worked, but the heating flues in the walls are not used.

For working with Warora coal, a furnace so high as that built by Mr. Ferrie, at Monkland, would, of course, be unsuitable, but it is possible that this fuel may be found to work, satisfactorily, in a much lower furnace of similar form. Even in a furnace 40 feet high, the working will be economical only if very hot blast is used, and it will be a matter for trial whether or not the coal should be partly or wholly coked before it is charged.

The experiment may be tried, with least expense, by altering the existing furnace at Warora, increasing its height to 40 feet and reducing its greatest diameter to 5 feet. In the Ferrie furnace, at the Monkland Works, the mean cross section of each retort is about 28.25 square feet, and its mean circumference is 21.4 feet; the same ratio of circumference to area as in a circle 5.28 feet in diameter.

The depth of the hearth, below the tuyeres, may also, I think, be made 6 or 9 inches less, with advantage, in so small a furnace. I add a tracing, showing the alterations I would suggest.

With the altered furnace, and using the same blowing and blast warming apparatus as before, the iron smelting experiment should then be repeated, under the charge of an experienced furnace manager, one used, if possible, to smelting with raw coal; and if liquid pig iron of any kind is obtained, and the furnace works regularly, the experiment may be considered successful.

Trials should be made both with raw coal, as before, and with coked coal, coked in heaps on the Staffordshire plan. This mode of coking is described and illustrated in the first volume of Dr. Percy's Metallurgy.

It is simple, and involves little outlay for plant. The coke should be screened, before use, and only so much as is retained by a 1-inch or $1\frac{1}{2}$ -inch riddle should be charged into the furnace.

The iron produced will probably be white, full of sulphur, and useless for any purpose, and it will be made only at the cost of an enormous expenditure of coal; but if it can be made at all, if the coke is sufficiently hard to render the working of the furnace possible, the use of a larger furnace, on Ferrie's plan, divided by internal cross walls, so as to offer as much resistance, from friction, to the descent of the charge as is afforded in the experimental furnace, and the use of highly heated blast, will reduce the consumption of fuel to a reasonable amount, and will make the metal good and serviceable.

Mr. Bell has pointed out that the effect of hot blast, in promoting economy of fuel in a blast furnace, is precisely the same as that of increasing the height of the furnace. Thus, at Lilleshall, by increasing the height of the cold blast furnaces from 53 to 71 feet, the consumption of coke, in smelting 43 per cent. ores, has been reduced from 40 cwt. to 27 or 28 cwt. per ton of pig iron made; as small a quantity of coke as would have been required in the old furnaces, 53 feet high, if they had been blown with air heated to between 800° and 900° Fahr. (Chemical Phenomena of Iron Smelting, page 356.)

While highly heated blast may replace height of furnace, without affecting the consumption of fuel, the economy that may be attained by these two agencies, jointly, is limited by the greater or less facility with which the ore is reduced, so that, while very hot blast is of doubtful advantage in furnaces so high as those of the Cleveland district, it effects a remarkable economy and a great improvement in the metal produced, in the case of furnaces which, owing to the softness of the fuel or the ore, cannot be made very high, and for such furnaces the blast cannot be too hot. Thus, at Warora, if it is found that by adopting Mr. Ferrie's plan, a furnace, 40 feet high can be worked, it will be advantageous to use blast heated to the highest possible temperature. The heating of the blast is effected, without cost, by the combustion of the waste gases from the top of the furnace.

The hottest blast is that produced by Cowper's or Whitwell's firebrick stoves. Of these the Cowper stove is theoretically the best, and it is the less costly of the two, and occupies less ground space. It was not,

however, easily cleaned from dust, as it was first designed, and Whitwell's modification was introduced to overcome the difficulty; but it is claimed that, by recent improvements in their construction, Cowper's stoves may now be cleaned with ease, so that Whitwell's form has no longer any advantage. I enclose a pamphlet descriptive of Cowper's stoves, and some other papers relating to them.

Messrs. Cochrane & Co., smelting a refractory mixture of ores, in their furnace 54 feet 6 inches high, and with blast heated to between 1,400° and 1,500° Fahr. by these stoves, use—

Staffordshire coal,	..	..	..	..	..	..	19½ cwt.
Coke from ditto.,	..	..	..	..	..	..	14 "

per ton of pig iron made. Assuming that the coke contains 90 per cent. and the coal about 60 per cent. of fixed carbon, this is equal to 24·3 cwt. of carbon per ton of pig. In 1871, when the blast was heated in cast-iron stoves, to about 800° Fahr. only, the consumption of fuel, per ton of pig iron made, was—

Staffordshire coal,	..	..	..	..	..	..	35·87 cwt.
Coke from ditto.,	..	..	..	..	..	..	11·40 "

equal to about 31·8 cwt. of carbon per ton.

The principal difficulty in the way of producing good pig iron, for steel making, with Warora coal as fuel, if blast furnaces can be worked, will be that the coal contains rather a high percentage of sulphur, and that the pig iron will be liable to take up sulphur from it.

This may be prevented in several ways, and I do not anticipate that it will be a cause of any serious trouble.

The use of the very hot blast already advocated, and working the furnace with sufficient fuel to make No. 1 or No. 2 grey pig iron, will be one safeguard. It is well known, that in any blast furnace in which sulphur is contained in the charge, it may be kept to a great extent out of the iron by working the furnace hot and making the metal very grey. If, from any cause, such as greater dampness of the air or of the materials, the furnace happens to make less grey or white iron, the metal is much more contaminated with sulphur, and the less grey it is the more sulphur it contains. White iron, from the same furnace and the same charge, contains often more than 20 times as much sulphur as No. 1 grey iron.

Another precaution that should be adopted, to keep the metal free from sulphur, is to add as much limestone to the charge as is consistent

with keeping the slag sufficiently liquid. To admit of working with a very basic and therefore a comparatively refractory slag, blast as hot as possible is again advantageous, as it keeps the hearth of the furnace at a higher heat.

It is difficult to estimate, exactly, how much Warora coal will be needed in the blast furnace, if it can be worked, but assuming that 35 cwt. of fixed carbon, or 80·6 cwt. of coal, will be required per ton of No. 1 or No. 2 grey pig iron made, and that the ores used will be, as in the former trial, equal parts of Lohara and of Ratnápúr ore, the ratio of silica to alumina, in the earthy matter of the charge, will be as 100 to 41·5, and with this proportion of alumina, a slag containing 48·5 per cent. of lime will be sufficiently fluid to run from a hot-blast furnace. To make such a slag, if the pure Vindhyan limestone is used, of which Mr. Hughes gives an analysis, 25·1 cwt. of it will be required, and the materials to be used per ton of pig iron made will be—

	Cwt.
Coal,	80·6
Lohara iron ore,	16·2
Ratnápúr iron ore,	16·2
Vindhyan limestone,	25·1

With these proportions, the slag per ton of pig will be about 28·8 cwt., or rather less than in average Cleveland practice. In the experimental cold-blast furnace, little more than half this amount of limestone should be used, in proportion to the coal, or the slag will not be sufficiently liquid.

Some of the rich manganese ore that has been found near Kamptee may also be added to the charge, with advantage, if the metal produced is found to contain too much sulphur. Spiegel-eisen, a pig iron containing from 5 to 20 per cent. of manganese, though smelted with coke, contains no sulphur; the addition of sufficient manganiferous ore to a blast furnace charge to put 2 per cent. of manganese into the metal reduces the sulphur contained in it from 0·2 or 0·3 per cent. to 0·05 or 0·08 per cent.; and pig iron containing 3 per cent. of manganese never contains more than a trace of sulphur.

If pig iron containing less than 0·1 per cent. of sulphur can be produced, the making of it into steel will present no difficulty. It may be treated by either the Bessemer or the open hearth process. I send with this a copy of a paper on steel making that I read some time ago before the Institution of Civil Engineers, in which both are described.

The Bessemer process is preferable, in working from pig iron, for making steel suitable for rails, tyres, and plates, where the production required is large; but it cannot be carried out on a small scale; and thus, for a small output, the plant required is expensive, and the open hearth or Siemens' process involves less outlay. The Siemens' process is also the better fitted for making steel of the higher qualities. The cost, in England, of the open hearth plant required to convert 100 tons of pig iron into steel ingots, per week, would be, including building and all accessories, about £5,000.

In making steel by either the Bessemer or the open hearth process, from 0.5 to 1 per cent. of manganese, in the form of spiegel-eisen or ferro-manganese, must be added to the metal. If steel making becomes established at Warora, this manganese alloy may be made, in a blast furnace or cupola, on the spot, but at the first it had better be imported from Europe, and rich ferro-manganese, containing 50 or 60 per cent. of the metal, may be found the most advantageous, on account of the expense of carriage, as a small quantity only, 2 or 3 per cent. of the steel made, will be required.

IV.—*Working of the Minerals by Direct Processes.*

Mr. Ness, in his Report of the 12th October 1875, after giving the account above quoted of the trial he had made to smelt the Chánda ores with Warora coal in a blast furnace, a trial which he regarded as proving, conclusively, that it would be impracticable to work these materials in that way, mentions the Blair process of reducing rich iron ores to spongy metallic iron, and subsequently treating this for the production of steel, without making pig iron at all, and suggests that this mode of working may be found suitable for the treatment of the Wardha Valley minerals.

In consequence of this report, samples of Lohara and Pipulgaon iron ores, of Warora coal, and of limestone, were sent to England, for trial by different modes of direct treatment.

Mr. Ness superintended the experiments, and gives an account of them in another Report, dated Glasgow, 5th January 1878. In this, he expresses a decided opinion in favour of the Blair process, and advises the erection, at Warora, of a reducing or sponge making furnace on this plan, and of a crucible steel-melting furnace, for the melting of the sponge into ingots of tool steel.

The Blair process is, certainly, one of the most promising of the many that have been suggested for the production of malleable iron or steel from the ore, without first making pig iron; but, like nearly all such processes, nearly all of them, at least, in which coal can be used as fuel, it has the serious drawback that, so far as I have been able to learn, it is nowhere practically and commercially at work.

Mr. Blair carried it on, for some time, in works near Pittsburg, Pennsylvania, U. S. A., but these were closed three years ago, and since then it has not, I believe, been worked anywhere, except on an experimental scale by Mr. J. Ireland, of Manchester, who is joint patentee, with Mr. Blair, of some modifications of the process and forms of the apparatus.

The Chenot process is the only direct mode of treating iron ores, in which coal may be the fuel employed, that is known to be in practical use. This method was first brought before the public in 1851, and a great future was expected for it, but it has not in most cases been found to compete advantageously with the methods of manufacture in common use, and it is now in operation in two works only, at Baracaldo, near Bilbao, in Spain, and at Clichy-la-Garenne, near Paris.

The process is described, at considerable length, in Dr. Percy's Metallurgy, and an account of it, as practised at Clichy, is given in the "*Révue Hebdomadaire de Chimie Scientifique*" for September 7th, 1871. It consists, essentially, in exposing the ore, in pieces of about two cubic inches in volume and mixed with a fifth of its weight of wood charcoal, to a red heat in vertical retorts. The retorts used, in one instance, of which particulars are given by Percy, were 28 feet high, and 6 feet 7 inches long by 20 inches wide. Each held a charge of 2 tons of ore, with a corresponding amount of charcoal, and the reduction to sponge required an exposure of the mass to heat for three days. In some instances, where charcoal was abundant, the reduction was effected by the direct action of a current of hot carbonic oxide, driven through the mass of ore, and at once heating and reducing it, instead of by heat transmitted to the mixed ore and charcoal through the walls of a retort.

Mr. Sandberg studied the process, very fully, in 1862, and reported on it to the Swedish Board of Ironmasters, at Stockholm. He states that the reduction of the ore was never uniform or complete, and that it was necessary, in all cases, to pick over the sponge, separating the imperfect-

ly reduced portions, to be treated again. The reduced sponge was generally "sunk" into balls in a charcoal fire, and then hammered or rolled into bars. 1·6 ton of sponge, containing 93·6 per cent. of iron, yielded 1 ton of finished bars, with a consumption of 0·86 ton of charcoal in making the blooms, and 1 ton of coal in reheating these before forming them into bars. At Baracaldo, in 1862, bar iron was made in three different ways,—by the Chenot process, by puddling charcoal pig iron, and by puddling coke pig iron, and the costs of the three qualities were respectively 500, 450, and 400 francs per ton.

The difference between Mr. Blair's process and that of Chenot is in the mode of heating the mixture of ore and carbon charged into the retorts. Mr. Blair claims to have discovered that the irregular and slow reduction of such mixtures is due simply to their low conducting power for heat, and that if the mass is once heated up, throughout, to uniform redness, and merely kept from cooling, reduction will take place regularly through it, without any absorption of heat, so that no additional supply of heat will be required. This is contrary to the view of most metallurgists, who consider that in the reduction of iron ore by solid carbon a constant absorption of and demand for heat go on, but the results obtained by Mr. Blair and Mr. Ireland seem to establish it beyond question, and the Blair process may be regarded as a substantial advance on that of Chenot, so far as the production of reduced spongy iron is concerned.

In Mr. Blair's first form of furnace, patented in England in 1872 (No. 1,795), the initial heating of the ore and carbon was effected by introducing the charge into the retort through an annular space, heated inside and outside, in which no part of the charge was more than three inches distant from the heating surface. "Each reducing furnace consisted of a group of three vertical retorts, each retort being 3 feet in internal diameter, and about 28 feet high, surrounded by an outer casing of brickwork, leaving a combustion chamber between the inside of the brickwork and the outside of the retorts. The retorts and outside brickwork stood upon a cast-iron entablature, supported on columns 12 feet from the ground; below the entablature, and forming a continuation of each retort, were wrought-iron cylinders, each surrounded with a water jacket, for more quickly cooling the iron sponge, and having at the lower extremity a sliding sleeve for discharging it. In the top of each retort a cast-iron pipe or thimble, 2 feet in diameter, and about 6 feet long, was

inserted, leaving an annulus of 6 inches between it and the inside of the retort.

"The retorts were heated externally, by gas jets, the air for combustion being supplied through apertures immediately above each jet. When the retorts were thoroughly heated, and all in working order, the gas generated from the ore under reduction ascended up the inside of the pipe inserted in the top of the retort, and on meeting with air flamed, and so heated the pipe. The ore and carbonaceous matter were fed into the retort down the 6-inch annulus, between the retort and pipe, and forming a narrow column heated on both sides, were thoroughly heated up before reaching the wide retort below." (J. Ireland, "On the Manufacture of Iron Sponge by the Blair process," *Journal of the Iron and Steel Institute*, 1878, page 47).

This form of furnace seems to be referred to in paragraph 9 of Mr. Ness's Report of the 5th January 1878, but nothing like it is shown in the accompanying drawings.

In it, the reduction of the ore to spongy metal was effected in about 30 hours.

Subsequently Mr. Blair found that, by the addition to the charge of about five per cent. of lime, or of any alkali, the reduction was so much quickened that an ore which formerly required 30 hours to bring it to the metallic state could be perfectly reduced in 6 hours.

To take full advantage, however, of this possibility of more rapid reduction, it was necessary to devise some means of heating up the charge more quickly; and this Mr. Blair proposes to do, where fuel sufficiently free from sulphur is to be had, by forcing a current of hot carbonic oxide through the mass, much in the same way as in the Chenot direct heating arrangement, except that Mr. Blair adds carbon and lime to the charge of ore, instead of using ore alone. Such a furnace, according to Mr. Ireland (*op. cit.*, page 50), with a retort 5 feet in diameter in the upper and 6 feet 6 inches in the lower part, by 16 feet high, will reduce 200 tons of ore to the metallic state weekly.

As charcoal is not to be had as fuel at Warora, and the Warora coal contains a good deal of sulphur, a furnace such as that just mentioned would not be suitable there, and "therefore," as Mr. Ireland writes in the paper already quoted (page 51), "the old form of furnace must be used, in which the heat is transmitted through the retort; but here,

again, some different arrangement must be made to heat up the ore more quickly. The writer ultimately concluded to abandon the inserted pipe or thimble, and divide this part of the retort into a number of smaller ones, so as to present as small a column of materials to the action of the heat as possible. A small furnace, some 21 feet in height over all, was erected on this principle, with a reducing retort about 18 inches diameter and 10 feet 6 inches high, and a cast-iron pipe on the top, $8\frac{1}{2}$ inches diameter, to heat up the ore. This furnace works well, and has been in constant operation since September last. Some 20 tons of the Indian ore have been operated on, and iron sponge of uniform and excellent quality produced, part of which has been since made into first-class tool steel, and some of it melted in a cupola into pig metal..... Various other ores have been reduced in this furnace with the same uniform result.

“ Though of small dimensions, this reducing furnace is on the principle proposed for working with transmitted heat, and, in furnaces of larger diameter, the number of small heating retorts, placed on the top of the larger or reducing one, will be increased, as the diameter of the latter increases; thus, a reducing furnace of 3 feet diameter will have four small retorts above it, and 5 feet diameter will have seven. The top of the large retort is arched over, against a circular key-brick, having a hole through its centre, one of the small retorts standing on the top of it. The remainder are placed round, each resting on two of the arches, so that the ore, &c., when heated, falls down between the arches into the large retort below. The spaces between the arches being almost square, and the small retorts round, a space is left at each corner, through which the gas generated from the ore under reduction can escape into the combustion chamber round the small retorts, thus helping to heat them. To cool the iron sponge, as quickly as possible, after reduction, it is split into three or more columns (according to the size of the furnace) in the wrought-iron cylinders below, each cylinder being surrounded by a water jacket, through which a slow current of cold water is passed, and on being discharged from the mouth pieces, is sufficiently cool that oxidation does not take place. A reducing furnace of this description, 5 feet diameter and 40 feet high, will reduce 60 to 70 tons of ore to a metallic state weekly, and the cost is about £600.”

No mention is made of this construction in Mr. Ness's Report; but it,

or something like it,—some arrangement in which the ore and the gases from the fuel are kept apart, while, at the same time, a rapid and thorough initial heating of the charge is provided for,—will probably be the best adapted for treating the materials of the district, if the Blair process is employed.

The density of a sample sent to me, from the India Stores, of iron sponge reduced by the Blair process from Lohara and Pipulgaon ores, is 102 or 103 lbs. per cubic foot.

In the production of metallic sponge, by Mr. Ireland, from these ores, Warora coal was the reducing agent used, and the reduced metal contained in consequence a very sensible amount of sulphur. As it would be difficult to obtain an average sample of the sponge, for analysis, on account of its toughness, the proportion of sulphur that it contains may be assumed to be the same as that in two samples of steel made by melting it, in crucibles, with wood charcoal.

These were marked, respectively, F and G (*see* Mr. Ness's Report, of 5th January 1878, paragraphs 22 and 29), and contained the following amounts of sulphur:—

In the sample F,	..	..	..	..	..	Per cent.
" " G,	..	..	..	..	..	0·327
						0·133
				Mean, ..	..	0·230

This is a proportion which, though admissible in tool steel, would render larger ingots of soft steel, such as that for rails, tyres, plates, &c., unforgeable, and if the sulphur cannot in some way be kept out, it will be necessary either to abandon the hope of being able to make rail or plate steel by the Blair process from these materials, or to use wood charcoal, with the ore, in the reducing retorts.

Some experiments that I have made in the matter lead me, however, to believe that by the use of lime, mixed with the ore, in the retorts, in rather larger quantity than Mr. Blair recommends, the proportion of sulphur that the reduced metal takes up may be kept so small as to be harmless.

Thus, when Lohara ore was reduced in a crucible, with an excess of Warora coal, and without any addition of lime, the resulting spongy metal contained in one trial 0·611, and in a second 0·65, per cent. of sulphur.

When 10 per cent. of slacked lime was added to the ore, the reduced

metal, brushed clean from adhering dust, contained only 0·082 per cent. of sulphur in one experiment, and 0·10 per cent. in a second, or on the average 0·091 per cent., an almost harmless amount, as rail steel containing even 0·15 per cent. of sulphur is forgeable, if it contains also 0·8 or 1 per cent. of manganese.

In another trial, with the lime in small pieces, about the size of mustard seed, and free from dust, in using 10 per cent. of lime, the reduced metal contained 0·109 per cent. of sulphur, and with 15 per cent. of lime it contained only 0·054 per cent.

When Lohara ore was reduced with wood charcoal, the sponge contained only traces of sulphur.

These results correspond well with the analyses, above quoted, of steel melted from sponge made by the Blair process, with the addition of 5 per cent. of lime to the ore. This contained 0·23 per cent. of sulphur. I found that the ore reduced by Warora coal, without lime, contained more than 0·6 per cent. of sulphur, that with 10 per cent. of lime it contained about 0·1 per cent., and that with 15 per cent. of lime it contained only 0·054 per cent.

In practice, the ore would be mixed with coal and with the necessary proportion of lime, 10 or 15 per cent. in powder, or in very small pieces, and passed through the reducing retort, and then, as the lime, after reduction, will contain nearly all the sulphur that was present in the coal, it should be separated, as completely as possible, by passing the spongy metal through a revolving screen, in which the friction of the pieces against each other will knock off the greater part of it. Even if some lime containing sulphur is left in the sponge, the sulphur will probably pass, in the subsequent treatment, with the lime into the slag, and will not affect the metal.

It may be assumed, from the above, that good iron sponge can be made practically and cheaply at Warora, from the Chánda ores; but, even granting this, the treatment of it, for the production of merchantable iron or steel, remains still a matter of difficulty.

Chenot's method of "sinking" the sponge into balls, in a charcoal fire is inapplicable, as charcoal is not to be had at a sufficiently low price, and, as Mr. Ness found, (Report, 12th October 1875, para. 5), the use of coal instead of charcoal, in admixture with the ore, is impracticable, on account of the large amount of ash that it contains.

It is possible that compressed blocks of sponge from the richer ores, alone or mixed with suitable fluxes, may be heated in a welding furnace, and worked into blooms sufficiently clean to make merchant iron; or the sponge may be balled up in a bath of melted oxide of iron, or on a cinder bottom, in a puddling furnace, and so worked into blooms and bars. Mr. Blair employed this latter plan, to some extent, at Pittsburg. He balled up the sponge, in some cases, in an auxiliary furnace, before charging it into the melting furnace, and states that when the balling is done in a gas furnace, very little of the sponge is oxidized.

The quality of the metal obtained, and the amount of waste, in these modes of working, must be determined by trial, and, in the event of the failure of all such plans, the sponge may still be made into steel.

By Chenot's mode of working, steel is made from the sponge by fusion in crucibles. The sponge is crushed, mixed with charcoal or other carburetting materials, compressed into little cylindrical blocks, and melted in the ordinary way.

Fusion in crucibles is also the mode of treating the sponge proposed by Mr. Ness for adoption at Warora. In the experiments mentioned in his Report, the sponge, as it came from the reducing retort, and without compression, was charged into the crucibles, together with a little charcoal, and melted down.

This is an expensive mode of working, more especially as the sponge, even when compressed, is more bulky than cut up bar iron or broken blister steel, so that while the expenses of crucibles, fuel, and labour are much the same as in melting compact metal, the outturn of the furnace is less. It is a process, also, that is adapted only for making small ingots of hard steel, such as is used for tools. When softer steel is made, the expenses of working are much increased, owing to the higher temperature that is required to melt it, and the consequent increase in the consumption of fuel, increased wear of the furnace and the pots, and decreased output; and the collection into one or two large ingots of the small quantities of metal melted in a number of pots is also troublesome and expensive.

Mr. Blair, in his works at Pittsburg, adopted the open hearth or Siemens-Martin method of melting the sponge into ingots. This is the only practicable mode of making from it the softer and cheaper qualities of steel, such as those used for bridge work, and for rails, tyres, plates, &c., but, as it was carried out by him, it has the disadvantage that a consid-

erable proportion of pig iron is required, together with the sponge, and that the waste from oxidation is great.

Mr. Blair used pig iron to form the initial bath, and the sponge was thrown into it, either cold, in loose pieces as it came from the reducing furnace, compressed into blooms 6 inches in diameter by 12 to 18 inches long, pressed into blooms or "tar plugs" with 8 per cent. of coal tar, or finally heated to welding on the cinder bottom of a puddling furnace, balled up, and charged into the melting furnace in a form like that of unhammered puddled balls.

The tar plugs and most of the blooms were heated to redness in an auxiliary furnace, and charged hot into the melting furnace; the loose sponge was thrown in cold.

The tar plugs were used to carburet the bath, and reduce the proportion of pig iron needed, and it was Mr. Blair's object to dispense in this way with pig iron, if possible, altogether, but I am not aware that he succeeded in doing so.

Mr. I. L. Bell, in the account he gave, in a paper read before the Iron and Steel Institute, of his visit to the United States, in 1874, commented on the Blair process somewhat unfairly, as those interested in it thought, remarking more especially on the amount of waste incurred in melting the sponge, and the correspondence that ensued contains some of the most reliable information that has been published as to its working.

In one series of eleven casts, at Mr. Blair's works, the materials used were:—

			Lbs.	Lbs.	Per cent.
Pig iron,	..	..	..	23,816	30·8
Scrap steel,	..	..	..	14,161	18·8
Tar plugs,	..	..	13,255	31,871	41·2
Hot sponge,	..	..	10,500		
Cold sponge,	..	..	8,116		
Spiegel-eisen,	..	..	..	7,531	9·7
				<u>77,379</u>	<u>100·0</u>

Deducting 8 per cent. for tar from the 13,255 lbs. of tar plugs, say 1,060 lbs., leaves for the gross quantity of sponge 30,811 lbs.; and again deducting one-eighth from this, for earthy matter (silica, alumina, &c.), say 3,852 lbs., the actual metallic constituents of the 11 charges stand as follows:—

			Lbs.	Percentage of charge	Percentage of yield
Pig iron (as before),	..	..	23,816	82.9	38.5
Scrap steel,	..	..	14,161	19.5	22.9
Iron in sponge,	..	..	26,959	87.2	43.6
Spiegel-eisen,	..	..	7,531	10.4	12.2
			<hr/>		
			72,467	100.0	
Steel produced (ingots and scrap),..			61,870		
			<hr/>		
Loss,			10,597	equal to 14.6 per cent. of the charge.	

In two charges of sponge, made by the Blair process by Mr. Ireland, that were melted to steel for rails at the Panteg Steel Works, Monmouthshire, in May 1875, the results were very similar. The sponge was thrown loose into the bath of pig iron, without any preliminary treatment. I am indebted for the particulars of these to the Managing Director of the Company. They are as follows, the weights being reduced, as in the American example, to pounds:—

			117 C. Lbs.	118 C. Lbs.
No. 8, Hematite pig,	..	..	2,779	9,254
Sponge,	..	..	3,052	9,824
Spiegel-eisen,	..	..	416	1,703
			<hr/>	<hr/>
Total charge, ..			6,247	20,781
			<hr/>	<hr/>
Steel produced (ingots and scrap),..			4,349 lbs.	16,037 lbs.
Carbon,			0.86 per cent.	0.57 per cent.

Assuming, as before, that the sponge contained one-eighth of its weight of earthy matter, the corrected weights and percentages will be as under:—

Charge, 117 C.				Percentage of charge	Percentage of yield
			Lbs.		
Pig iron,.. ..	..	..	2,779	47.4	63.9
Iron in sponge,	..	..	2,670	45.5	61.4
Spiegel-eisen,	..	..	416	7.1	9.6
			<hr/>		
Total metallic charge, ..			5,865	100.0	
Yield,			4,849		
			<hr/>		
Loss,			1,516	equal to 25.8 per cent. of the charge.	
Charge, 118 C.				Percentage of charge	Percentage of yield
			Lbs.		
Pig iron,	..	..	9,254	47.3	57.7
Iron in sponge,	..	..	8,596	44.0	53.6
Spiegel-eisen,	..	..	1,703	8.7	10.6
			<hr/>		
Total metallic charge, ..			19,553	100.0	
Yield,			16,037		
			<hr/>		
Loss,			8,516	equal to 18.0 per cent. of the charge.	

In Mr. Blair's practice, 50·7 tons of pig iron and spiegel-eisen, together, were used, in addition to sponge, for each 100 tons of steel ingots and scrap made, or estimating the yield of merchantable steel at 80 per cent. of the ingots, about 65 tons of pig and spiegel-eisen would be needed, for every 100 tons of finished steel produced.

The results at Panteg were still worse, the proportion of pig iron and spiegel-eisen used there having been about 70 tons, for 100 tons of ingots made, or nearly a ton of pig iron for each ton of merchantable steel turned out.

These proportions of pig iron used to steel turned out are not, it is true, the lowest that can be counted on, as, in the charges at Mr. Blair's works, part only of the sponge used was in the form of tar plugs, and part was charged cold and without compression. The melting furnace used was also defective in design, and inferior in working to those now employed. At Panteg, also, the sponge was all thrown loose and cold into the bath, and it had, I believe, been in stock for some time, and may have become partly oxidized.

Still it is evident that the success at Warora of the open hearth Blair process, as it was worked at Pittsburg, is very uncertain, as it can be employed there only if pig iron of suitable quality can be made on the spot, or if the use of it can be altogether or almost altogether dispensed with.

Mr. Ireland proposes to melt the sponge first, in a cupola, to white cast-iron, with coked Warora coal, and to charge this into the open hearth furnace in a liquid state, and if this can be done, it will obviate the difficulties of the process most satisfactorily. I fear, however, that unless charcoal can be used in the cupola, the plan, as proposed, will be found impracticable.

The avidity with which melted steel or melted white cast-iron takes up sulphur is so great that, if coke is the fuel used, the metal will be so contaminated with sulphur as to be useless.

White pig iron, from a blast furnace in which coke is used, contains, as already mentioned, a much greater proportion of sulphur than grey iron from the same furnace; in melting grey pig in a cupola, for the open hearth steel process, with coke, if the tuyeres are adjusted so as to burn out some of the carbon and silicon from the metal, and make it white, it at once takes up between 0·2 and 0·3 per cent. of sulphur; and in crucible steel-melting, with coke, in which, when a pot bursts, the steel runs

through the fire into the ashpit below, the runnings, in their momentary passage through the fuel, take up so much sulphur as to render them almost worthless.

A trial of the plan, carried out at Woolwich Arsenal, and described in paragraphs 30, 31, and 32 of Mr. Ness's Report of 5th January 1878, shows the same result. Sponge, reduced from the Chánda ores, was melted in a foundry cupola with English coke, and tapped out as white cast-iron. Steel made from a portion of this metal was quite unforgeable, and Mr. Riley, on analyzing some of it, found that it contained, as a mean of two determinations, 2.58 per cent. of sulphur. In another sample, supposed to be part of the same charge, Mr. Riley found only 0.344 per cent. of sulphur; but this, though still more than twice as much as is admissible, under any circumstances, in mild steel, is so much less than I should have expected, and so much less than was found in the former sample, that I cannot but think that there has been an error in the sampling or in the marking.

It is possible that, by using very hot blast in the cupola, instead of cold air, and by charging as much lime with the sponge as is found to be consistent with retaining the slag of such a composition as to be sufficiently liquid, or by charging manganese ore with it, the sulphur may be kept out of the metal, and this is a direction in which further experiments may be made with a fair prospect of success.

The cupola in which the sponge was melted at Woolwich was only 13 feet high, and the blast furnace trial at Warora showed that the coal, or the coke made from it, might be worked in a furnace of nearly twice that height, if not in one still higher.

Where good coal or coke is to be had, it would be needless to divide the blast furnace process into two stages, making reduced spongy iron in one operation, and melting this in a cupola in a second, but as, from the softness of Warora coke, it is doubtful whether a blast furnace sufficiently high to be economical can be worked with it, this mode of treating the ore may prove to be the cheapest and best, if only by the methods of working suggested the metal obtained can be kept sufficiently free from sulphur.

The trials made by Mr. Ness to produce malleable iron from the Chánda minerals, by heating together mixtures of powdered ore and coal, were not encouraging, the yields being irregular and small, and the metal, in

most instances, very red-short. It contained little sulphur, two samples of iron reduced thus in Dr. Siemens' rotating furnace, at Towcester, containing respectively, by Mr. Riley's analyses, 0.021 and 0.028 per cent. of sulphur, and a third, made in a Siemens' puddling furnace, at Holytown, near Glasgow, containing only 0.015 per cent. Its bad quality was thus due rather to the quantity of earthy matter, probably ash from the coal, that it contained than to sulphur, and it is possible that, by adding suitable proportions of lime and of manganese ore to the charge, as fluxes, this earthy matter may be removed, and good iron obtained.

It is not likely, however, that this mode of working will be able to compete with the reduction of the ore, in the first instance, to sponge, and the welding of this together and balling of it up, in a puddling furnace.

The output of a furnace working raw ore will be less, the waste of iron in the slag will be greater, and the metal will be mixed with much more earthy matter, and will be less easily obtained sound and free from red-shortness.

V.—*Conclusion.*

In conclusion, I am of opinion—

1. That iron and steel making in the Chánda district must be regarded as still wholly experimental, and that, if furnaces or other apparatus are put up, they should be all on a small scale.
2. That the iron ores of the district are of remarkable richness and purity, and that good limestone for smelting is to be obtained, but that the softness of the Warora coal, when charred, renders the successful working of a blast furnace with it very doubtful, and if a furnace can be worked, the low percentage of fixed carbon that the coal contains, together with the refractory character of the ores, will render a large consumption of coal needful per ton of pig iron made.
3. That if any coal can be found in the district that yields a harder coke, it may be worked in a blast furnace without difficulty, and that if a coal can be found that contains more fixed carbon, it will be more economical than Warora coal in the furnace, and less of it, in proportion to the pig iron made, will be required.

The relative hardness of the cokes of different coals may be compared

by testing them, under similar conditions, in a revolving drum, like that used in the experiments described above. Cast-iron or leaden balls will be more suitable than a stone for crushing the coke.

4. That the only form of blast furnace that is at all likely to work well, with Warora coal or coke, will be a low furnace, about 40 feet high, with the shaft divided into compartments by vertical cross walls, on Mr. Ferrie's plan, so as to partly support the charge, by friction against the brickwork, and keep it from crushing together too heavily in the lower part of the furnace.
5. That even with a furnace 40 feet high, the blast should be very hot, heated to $1,400^{\circ}$ or $1,500^{\circ}$ Fahr. by fire-brick stoves, preferably by stoves on Mr. Cowper's plan.
6. That the question whether a blast furnace, 40 feet high, can be worked with Warora coal may be determined, very simply, by altering the experimental furnace at Warora, increasing its height to 40 feet, and reducing its diameter to 5 feet, and working it with the same blowing and blast warming arrangements as before; and trying whether, in such a furnace, pig iron can be produced with this coal.

If it can, there need be no hesitation in going to the expense of putting up a larger furnace and hot blast stoves.

7. That spongy iron, of good quality, may be made at Warora by the Blair process, and that there will be no difficulty in making the sponge into steel, by fusion in crucibles, but that this mode of working is expensive, particularly in melting a material of such low density as the metallic sponge, and that it is suited only for making small ingots of hard steel, while, as considerable skill is required to make the steel of regular hardness, suited to various purposes, this process, too, must be regarded as experimental at the first.
8. That the open hearth mode of working is the only plan fitted for producing steel cheaply, and on a large scale, from iron sponge, but that, as it was carried out by Mr. Blair, it required the use of so much pig iron, in addition to the sponge, as to be unfitted for adoption at Warora, unless pig iron of suitable quality can be made on the spot; and that Mr. Ireland's proposed modification of it will also be inapplicable, unless means can be found to

keep the metal produced by melting down spongy iron with Warora coke, in a cupola, nearly free from sulphur.

9. That the problem how to keep sulphur out of the metal thus obtained has an important bearing on the prospects of making steel cheaply, and in quantity, in the Chánda district, and that experiments to determine whether it can be solved are very desirable.

These may be made in England, and with English foundry coke, as, if metal nearly free from sulphur is obtained with such coke, equally good results may be reached with Warora coke, as this contains no exceptionally large proportion of sulphur, and the trial at Warora proved that it can be worked in a furnace at least 24 feet high. The experiments should consist of melting spongy iron from the Chánda ores, in a cupola, with manganese ore, and with the greatest possible proportion of lime, together and separately, and determining in each case the proportion of sulphur in the metal tapped out. Cold blast may be used, first, and if a sufficiently good result is not obtained with this, very hot blast, heated by Cowper's stoves, should be tried. Mr. Cowper may be able to arrange for the carrying out of the experiments with hot blast at one of the works where his stoves are in use.

10. That the sponge from the richer ores may possibly be balled up into lumps pure enough to be made into bars of merchant iron, but that this is a matter to be determined by trial.

Meantime, a small Blair reducing furnace, such as Mr. Ireland proposes, and a 6 or 12 pot crucible steel-melting furnace may be prudently put up at Warora, as there is no doubt that good spongy iron and excellent tool steel can be made from the materials of the district.

I have no practical knowledge of the Bicheroux steel-melting furnace which Mr. Ness recommends, and cannot give any opinion as to its working.

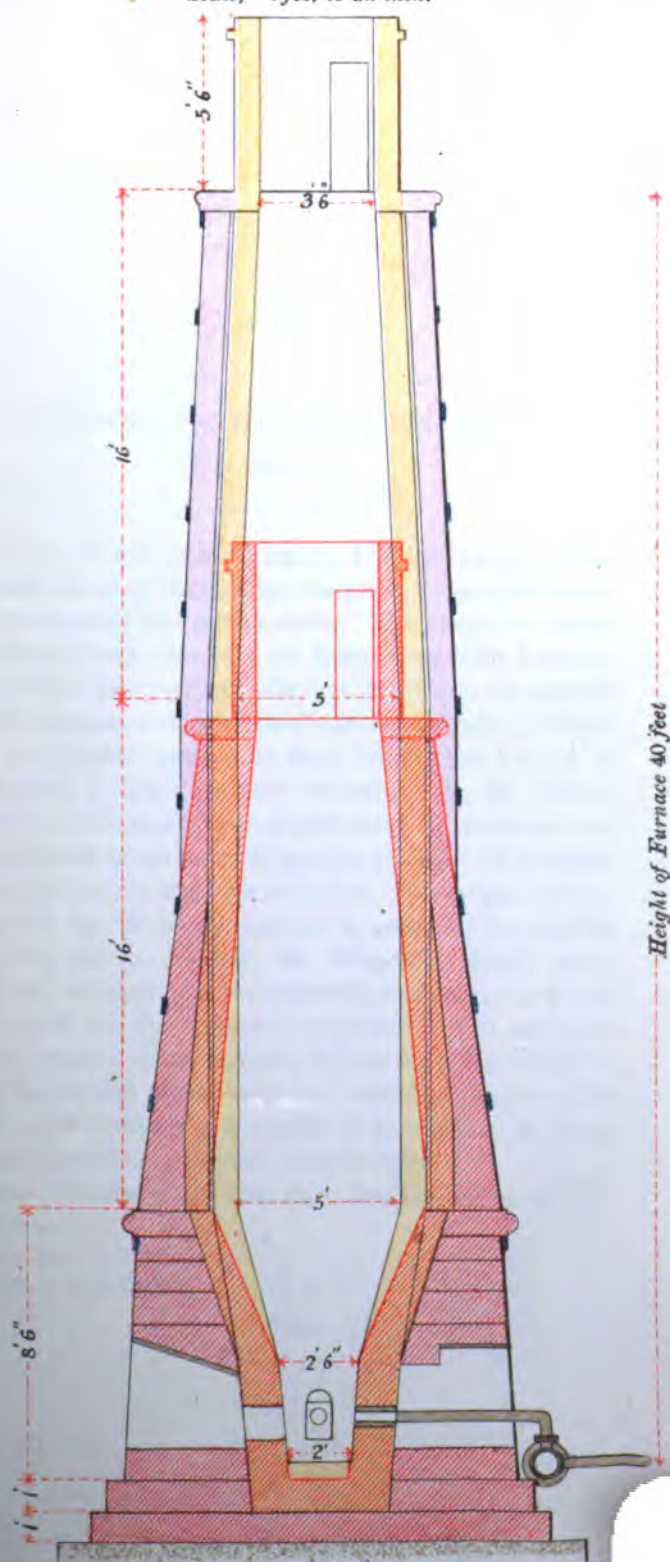
I have confined myself, in this report, to the consideration of some of the technical questions bearing on the prospects of iron and steel making in the Chánda district, and have not attempted to make any estimates of the costs of production.

CLYTHA PARK ROAD, NEWPORT, }
16th February, 1879.

W. H.

REPORT ON THE IRON AND COAL FROM THE CHANDA DISTRICT OF THE CENTRAL PROVINCES OF INDIA

Scale, 6 feet to an inch.



100

100

No. CCCXXVIII.

INTER-OCEANIC CANAL PROJECTS.

[*Vide* Plate.]

EDITOR'S NOTE.—In last quarterly number I published a paper about the Inter-Oceanic Canal by Mr. Menocal, imagining it was a plain statement of the advantages of the various routes. The discussions on the paper in the two following numbers of the Transactions of the American Society of Engineers show very decidedly that this view is not accepted generally by the members, no less than twelve gentlemen having “offered remarks” of considerable length. As these Transactions are not in general circulation, I reprint the first “discussion” by Mr. Walton W. Evans, as the most complete view of the through sea level advocates, and at all events it will be allowed to be amusing reading. Of the other members some are for one some for the other. The general opinion seems to be that Mr. Menocal’s estimate is much too low for the Nicaraguan route, and one member, Mr. Edward P. North, states that none of the estimates give the total cost, he writes—“It is well known that in addition to the engineers’ or absolute cost of any work, there are other expenses—some perfectly legitimate—which depend so largely on the honesty and discretion of the board of direction on the one hand, and on the confidence of the public in the scheme on the other, that it is almost impossible to correctly estimate them.

“An analysis of the cost of the Suez shows that the two items were in round numbers—

Absolute cost,	..	..	..	..	..	\$48,000,000
Expenses of administration,	..	..	..	..	..	50,000,000
Total,						\$98,000,000

"As in the present case there are rival projects in the field, and no route is now known that does not present complications, which though doubtless surmountable, will tend to alarm timid investors, and as the work is much further from the accumulated capital and low rate of interest of Europe, it may be assumed that even under Count de Lesseps' experienced guidance, these administrative expenses will amount to at least 115 per cent. in place of the 104 per cent. of the Suez Canal.

"As a careful location has been made only on one route, and that is now generally admitted to require revision in the matter of curves, locks, &c., no estimate of the absolute cost can be advanced as more than a rough approximation, but the general impression seems to be that it will be in the neighbourhood of \$120,000,000; if to this \$138,000,000 (115 per cent.) be added for administrative expenses, we will have the cost at completion \$258,000,000.

"It can hardly be expected that on the completion of this canal the routes of commerce will immediately change, and even if that were probable, the investors must wait for an increase born of the facilities afforded by the canal before they can hope to receive a satisfactory income from their expenditure.

"As even a small railroad enterprise, shortly after completion, passes through the various phases of floating debts and ingeniously-named mortgages—if happily it escapes the hands of receivers, this canal, if ever built, must probably see its immense capital nearly if not quite doubled before its dividends can equal $15\frac{1}{2}$ millions or 6 per cent. on the cost at completion."

The point noticed above that the surveys and data for any of the estimates are most incomplete is insisted on by most of the other members.

Mr. Julius W. Adams takes an entirely different view from all, and advocates a canal through the Isthmus of Tehuantepec, *vide Plate*. His argument is that the canal should be first for America, and should be entirely in the hands of America—"no European co-partnership." "The desire to make the Gulf of Mexico a closed American sea is as natural to us as a similar policy to other powers in regard to the Black Sea, the Caspian, the Zuyder Zee, and others." "There is no more reason why foreign nations should be allowed to guarantee the neutrality of an American thoroughfare than that the United States should be a

party to defend the British Channel, the Straits of Gibraltar or the Isthmus of Suez." "A canal terminating in the Gulf of Mexico would be easily protected in time of war, and by making, in case of need, the Gulf a closed sea, our merchant marine would be safe from all attack, and our relations with the Pacific could be sustained without any interruption." But while starting on this basis as the most important point, he gives tables of routes, results of which are somewhat shown in the Plate, to show that independently of this, the upper is the better route. He states there is ample material and excellent climate on the upper route, but says there are no surveys on which to base an estimate. Comparing however by length and lift with Mr. Menocal's estimate for the Nicaraguan at the same rates, he runs out a rough estimate of 58 million dollars, against the Nicaraguan 66 millions. He allows that the transit will be 67 hours against Mr. Menocal's 38½, and he concludes as follows:—

"Whatever may be the advantage in point of time of a transit at Panama over that at Nicaragua, as we are dealing with the latter entirely in this comparison, we have to state that the passage of the Tehuantepec Canal will require one day more than the canal at Nicaragua, or, at the outside, two days. As regards the objections to locks—whatever route be adopted, even the through cut, so called, if it can be built, will require a tide-lock, at least, on the Pacific. In admitting that mean tide on either side would be at the same time the rise on one side of 20 odd feet, and on the other of 1½ feet, would require a tide-lock for adjustment of current. The fact that the Red Sea level was *traditionally* some 30 feet above the Mediterranean, and results demonstrated in a canal of 90 miles in length, connecting the two, that the difference was really inappreciable, has no bearing whatever upon this question.

"The route which, as we have seen, while giving all proper facility to European commerce through American water-ways, still from its geographical position gives a proper preponderance to our domestic commerce, requires the use of lift-locks. Shall 24 or 48 hours additional time for its passage, and the bugbear of the danger of such transit, which differs but in degree, and not in kind, from the most favorable route which European interests can point out, deter American enterprise from carrying out what the interests of her growing domestic commerce calls for, and leave her to gather such crumbs as older nations have determined shall be her share?

"Public opinion is beginning to express itself, in a manner not to be mistaken, adverse to any foreign occupancy among the small States of Central America, where a question of the infringement of the rights of such occupants by the local government could so easily be made the pretext for the interference of a foreign power, ostensibly for the protection of the rights of its own citizens, but virtually to deprive this Government of the control of her own domestic trade. This feeling has been aroused by the late movements of a French company at Panama. But, indeed, either at Panama or at Nicaragua, if a ship canal should be built under circumstances of control nominally favorable to this country, and in accord with the spirit of the Monroe doctrine, as we construe it, yet its location, although endorsed by high officials, would, as we have seen, be so much more favorable to foreign than to American commerce that the legitimate growth of the latter would be completely crippled; and to prevent such a consummation we must go still further, and refuse countenance or support, in any way, to the construction of a ship canal located at any point south of the Peninsula of Yucatan; or, in other words, south of the Isthmus of Tehuantepec. And the importance of enlightening our people as to the national bearing of this question of the location of a ship canal cannot be over-estimated. It is no longer *who* shall build it, nor *how*, but *where* it shall be built, that interests us as American citizens."

Discussion by WALTON W. EVANS.

I beg to offer a few remarks in discussion of Mr. Menocal's paper on the much-vexed project of the Inter-Oceanic Canal. I wish to give, first, my reasons for venturing an opinion:

1st. I have served for seven years as an engineer in the construction of canals.

2nd. I have had an experience in the construction of public works of over forty-two years.

3rd. I have crossed the Isthmus many times—partly by foot, by mule, by canal, and by rail.

4th. I have been detained on the Isthmus for weeks—by rains, revolutions, and want of transportation—before the railway was built.

5th. I have witnessed the heavens open their flood-gates, and seen the terrible washings the railway was subjected to.

6th. I have lived in earthquake countries for eleven years, and have witnessed the convulsions of Nature on the Isthmus as well as in Peru and Chile.

7th. I have, for over thirty years, made a study of this most interesting problem of cutting a canal for the largest ships through the narrow strip that divides North from South America.

8th. And I have read with care most of the public documents published in reference to it, and am clearly of the opinion that the "San Blas" route for a sea-level canal is far preferable to the Nicaragua route, with locks, or any other route ever reported on.

I beg to present some axioms in reference to this great problem :

1st. A canal thirty miles long is preferable to one a hundred and eighty-one and one-quarter miles long.

2nd. A canal without locks is preferable to one with locks.

3rd. A canal that has good harbours at its *termini* is preferable to one with no harbour at either end.

4th. A canal built in a healthy region is preferable to one in an unhealthy region.

5th. A canal that can be navigated in ten hours is better than one requiring one hundred hours.

6th. A canal that will call for very small repairs is preferable to one requiring immense repairs.

7th. A canal that has a small "water-shed," but a sure supply of water, is preferable to a canal having a great "water-shed."

8th. A canal that is not on a line of drainage is preferable to one on a line of drainage.

9th. A canal that can pass a ship of any length is preferable to one that limits the length to far below that of many existing ships.

10th. A canal that is virtually a straight line is preferable to one with many curves, some of them very objectionable.

I have read with care Mr. Menocal's clever paper, and beg to take issue with him on some points. He starts off with the assertion that the matter is narrowed down to two routes—the Panama and the Nicaragua. I should have been better satisfied if he had said the San Blas and the Nicaragua, for I look on the Panama route for a sea-level canal as simply ridiculous. I intimated the same, but with less forcible words, to Count Ferdinand de Lesseps, in Paris. After many

years of study of this matter, and after for a time believing in the Nicaragua route as the proper one, I came to the conclusion that the San Blas route had many features in its favor that placed it far in advance of all others. I refer to the foregoing axioms for those features. I beg to say a word in defence of Count Lesseps. I have an impression that he is thoroughly honest, and find that is the opinion of all my friends in Paris who know him well. I think he was, in the conducting of the Congress, influenced by men who hoped to grow rich through the use of his name. He will soon see the error he has made when he reaches the Isthmus, and is made acquainted with the terrible destruction of the late floods. He said to me in Paris: "There is one point in this matter we must observe: wherever the canal is built *it must be a sea level canal.*" In this I fully agree with him; and I will add one more important engineering feature: it must not be built on any line of drainage, or across any line of drainage. What we require—what the world requires—is a perfectly reliable canal, that cannot by any accident run itself dry; that is perfectly secure against the accidents that can occur and do occur to all canals depending on dams and locks as working features, no matter how well and costly they may be built; if we cannot give the trade of the world such a canal we had better give it none.

I would not propose to run the San Blas canal into the Rio Bayano, but turn that river off into the Bay of Panama by a cut made expressly for it; this could not be done for the Chagres River, except at an expense of many millions. It is proposed to build the Nicaragua Canal in the Valley of the San Juan, and in close contact with the river for many miles. I would suggest to the advocates of that route, and to the capitalists who I am told stand ready and eager to put their money in it, to first visit the Valley of the Lehigh, in Pennsylvania, and view the ruins of what was, within my recollection, a canal that received the praise and admiration of everybody; it was built by skilled engineers; the money furnished by the most careful and long-headed Quakers of Philadelphia; it had locks of thirty feet lift, the greatest ever put on a canal; the water-shed of the Lehigh is very insignificant; all the owners slept, no doubt, quietly in the possession of what they supposed to be a very safe investment; but a storm came—a flood was the result; this little lamb-like river became a great, fierce tiger, bent on destruction; a weak point was found in the upper dam, the tiger poked his nose in it, a little leak

was started, and away went the whole structure; with it went every dam and lock on the whole river, and hardly left a wreck behind; no one ever had the courage to rebuild that canal. There are many among us that recollect the destruction of the Croton River Dam; placed at the initial point of the Croton Aqueduct, it was built under the plans and direction of that Nestor in American engineering, John B. Jervis; he was an old and skilled canal engineer. Who have we at the present day who is his superior? That dam was built on rock, where the best of materials and skilled workmen were to be had in profusion; but it went—carrying havoc in its course—and destroyed every bridge, dam, mill, factory, and building it could reach down to the Hudson River. I well remember this river above the dam, and its lamb-like character in summer, for I built a railway on its banks, and have many times crossed it on stepping-stones without wetting my boots. The European news of the past two days tells us of floods in Hungary, and that many danis have been carried away on branches of the Danube. I for one would rather trust to a tunnel than a dam. I have had a good deal to do with dams, and I feel towards them as Robert Stephenson once told me he felt toward railways, that he was afraid of them.

There are other things that I would be afraid of in the construction of a canal with elevated reaches on the side of a valley where such rains occur as are frequent in the San Juan region, I mean the melting and running of the embankments. Once on arriving at Panama on my way home I was told I could not cross the Isthmus, as there was a wash-out a few miles from Panama. I took a hand-car, went to see it, and found Col. Totten there making an embankment of sleepers. This same embankment had been washed out three times before, and every time it had been, when rebuilt, reinforced by a row of piles, close together, on the down-hill side. Col. Totten said to me, "You see this embankment could not go out down hill this time, so it has gone *up hill*." It had actually squashed out on the up-hill side, and had run very much as molasses would run; a horse or man going into it would soon have gone out of sight. To know the Isthmus and its rains, and what rains can do in the way of making running mud out of embankments, it is necessary to go there and see it, for no one can imagine it from any pen sketch. I have an impression that all the arguments that can be urged against the Panama route will hold good against the Nicaragua, while the Panama

route, adapted to have locks, has the advantage over the Nicaragua in the matter of length and harbours at the termini.

Mr. Menocal's estimate of cost appears to be made as many other estimates of cost of public works have been before his time, by dealing in too small figures, and making omissions. His estimate for drains (I suppose this covers aqueducts over side rivers, culverts over streams, changes of channels, waste-weirs, sluices, &c., &c.) is magnificently deficient, and I see no items for protection walls, inside and outside, puddle walls, lining to prevent leaks, gravel facings, &c., &c. Also draw bridges over the canal, light-houses, machine-shops, and whole villages of buildings for residences, &c., store-houses, &c., &c. I suppose these are all in the twenty-five per cent. for contingencies. I have found in practice that after estimating every item I could think of, the twenty-five per cent. for contingencies came in as a most comfortable assistant at the end. Captain Young, who built the Utica Railway, used to say that the only safe way to make an estimate, was to take the largest quantities you could get from the profiles, carry them out with the largest prices you ever heard of, add twenty per cent., and then double the whole. When the first estimate of the Hudson River Railway was made, there were many arguments offered to show that it could be built for about "half of nothing," the engineer gave the size and number of every arch and culvert required on the whole 145 miles, for each division. I, having a love of statistics, counted them, and found there were about sixteen or eighteen in all. Now, this same engineer had just before built the Croton Aqueduct over forty miles of the same route, and close to it, and had forgotten that he had built over three hundred culverts, arches, and bridges, on that forty miles. The protection walls for this railway, amounting to over 400,000 cubic yards, were estimated to cost fifty cents per cubic yard, and it was forgotten that the protection walls of the Croton Aqueduct (now nearly all, inside of forty years, replaced by better walls) cost \$1.75 per cubic yard. I mention these things to show how errors creep into engineers' estimates, even among the most conscientious—their zeal, their desire, their anxiety to see their project go down the throats of somebody, overrides their judgment and stores away in oblivion for a time all their hard-earned experience, making true at this day the old Roman motto, "*Men try to believe what they wish to be true.*"

The Nicaragua route calls for the construction of artificial harbours at each *terminus*. This is a most unfortunate feature of this route. Such things have to be approached with fear and trembling, and a pocket full of money, and after they are built and handed over as something to be proud of, they, or their parts, very often go on excursions up and down the coast, through the alluring enticements of the wind and the sea. Some have their usefulness nipped in the bud by a failure to find funds for their completion, as was the case with the Dover Harbour, in England. I had occasion to examine those works in 1853, and then came to the conclusion that although "John Bull's" purse was long and large and full, that he had better leave that work alone, and since then he has left it severely alone. The one long wall which I saw in 1853, I was again on in June of this year, and found it had neither grown higher, longer, nor more complete, and its partner had never been attempted. In March of this year I walked, or rather clambered, out for a short distance on the concrete breakwater for the harbour of Port Said, at the northern *terminus* of the Suez Canal, found that it was far from finished, and unless finished would in a few years be knocked to pieces and rendered useless. In November of 1878 I had a chance to examine the concrete works of the harbour at Algiers, built by the French, evidently at great cost. The waters of the Mediterranean had quietly or unquietly, as the case may be, just knocked a considerable part of it into a "cocked hat," and the Algerines were, in their faith, no doubt, praying to "Allah" to knock the "cocked hat" into "pi."

Artificial harbours are contrivances to be avoided, if possible: they are apt to give engineers sleepless nights, to deplete plethoric pockets, and vanish when called on by the winds and the waves.

I have some experience in sleepless nights produced by things of this kind, for I built out into the Pacific Ocean the first pier ever built on the whole coast of South America, that a big ship could haul alongside of. The "Brave south-west winds" as Maury called them, were my friends for thirty days out of thirty-one, then "Æolus" sent "Boreas" down to make things lively with his "big guns," and at the same time make an engineer's heart sink into his boots. During construction I often saw the northers rolling in the waters, which went over my pier from 20 to 30 feet high, and bid fair at times to carry the whole structure, with its 80,000 tons of stone, on to the beach.

Mr. Menocal estimates the locks between gates to be 400 feet long; a lock of this length will pass a vessel of only 360 feet. Thirty years ago vessels of 360 feet long were scarce articles; we have now lots of vessels of 450 feet, and vessels of over 500 feet are being built. Who can say what will be the length of vessels in another thirty years? The locks of the Erie Canal of 1825 could not pass boats of half the size that are now locked through.

The locks of the Delaware and Raritan Canal had not been in use thirty years before they had to be doubled in length. I came through the Suez Canal in March in a Peninsular and Oriental Royal Mail steamer from Hong Kong and Bombay, that was over 400 feet long; other steamers of that line are over 450 feet long. I saw a number of steamers in the canal, and judge that most, if not all of them, were over 400 feet long; it would be a sorry mistake to build a canal with locks that cost over \$300,000 each, and find that they could not pass these giant craft, for they are the cream of the business a canal company would seek.

The Suez Canal is virtually a straight line. When I arrived at Lake Timsah we found a huge steamer stuck in the mud in the lake, and a crowd of Arabs unloading her; the canal ahead was blocked; I took a steam pilot-boat, went ahead to see the difficulty, and found that a passing steamer had run into and sunk one of their large dredging machines; this once clear, the next day our Leviathan attempted the passage to Port Said, but we had hardly run in the canal a mile before our vessel run her bows into the right bank, her stern slewed around and went into the left bank; there we stuck for two hours, and in two hours more our craft was laid along side for the night, that being her second day in the canal; this steamer entered the canal at 4 P. M., March 22nd, and arrived at Port Said at 10 A. M., on the 24th, taking 42 hours to run just 100 miles in a sea-level canal, virtually one straight line. The very next mail steamer of the P. & O. line that came through after I did, ran into the bank, her stern swung into the opposite bank, and broke off two of the blades of her propeller. Accidents like this, of running into the banks, being apparently common on straight lines, it would be well to examine carefully into the manner of working these long steamers around the sharp curves of the proposed Nicaragua Canal.

We in America know that the English locomotives have a very un-

mannerly habit of jumping the track at sharp curves, which habit we in America have almost entirely eradicated from their vicious propensity by rendering them subservient to the ameliorating influences of a "Bogie," a mechanical persuader which accomplishes the object in a most satisfactory manner; if this admirable invention could be applied to a ship, we might overcome the difficulty; as yet I see no manner of making the application, but the Yankee brain is prolific, and some genius may work out the conditions of this important problem. Old canal men and sailors accustomed to handling these huge vessels will look with a smile on the estimate of $38\frac{1}{2}$ hours to pass through a canal $181\frac{1}{2}$ miles long, with many sharp curves and 22 locks; also the estimate of 20 minutes to a lock; to fill or empty a lock in 12 or 14 minutes would not be a difficulty, but that is only a small part of the time required to pass a lock; it must be recollected that a vessel has to be "slowed down" long before she reaches a lock, and in most cases come to a dead stop before she enters the lock, then to be hauled in slowly and with care, for if a large steamer, weighing with cargo 8,000 or 9,000 tons, enters or approaches a lock with any amount of headway on her, she will probably walk through the lock without asking permission, and in much less than 20 minutes. If any such trade as would certainly be offered to a sea-level canal were offered to a canal with locks, there would, most undoubtedly, be great detention at the locks, by one vessel finding another vessel in the lock, other vessels ahead of her, gates shut, lock empty, &c., &c. If any one thinks these large vessels can be started and stopped, and turned like children's toys, let him go down to the piers in New York and see one of these large steamers arrive and get berthed. I arrived in July in the *Britannic*, and we were full one hour from the time we touched the dock until the ship was hauled into her berth. Taking my trip on the Suez Canal as a base for calculation, I would make the time of passing the Nicaragua Canal as follows:—the speed was a mile in 25.2 minutes; 181.25 miles at 25.2 minutes per mile, 76 hours; 22 locks at $1\frac{1}{2}$ hours a lock, 33 hours; total 109 hours; or, say $4\frac{1}{2}$ days, and this may be put in opposition to one single day of ten hours in passing the clear, straight, unobstructed 80 miles of the San Blas route.

Mr. Menocal estimates the cost of the Nicaragua Canal at 66 millions dollars. Men with experience and analytical brains have criticised this estimate and found it deficient. I agree with them, and further believe

that the dimensions estimated are not such as a world's Canal calls for and should have, particularly in available width and depth, and more particularly when carelessly handled ships are to be encountered. In going out of Marseilles harbour just one year ago in a straight channel of double the width of the canal proposed, our French captain had all his yards squared; he met an incoming brig, his vessel did not touch the brig by fifteen feet, but his main-yard struck the foremast of the brig and snapped in the middle, broke the fore-top mast of the brig, and down it came with all its spars close to the spot where I was standing with some ladies.

In pushing and preaching the merits of the Nicaragua route, there appears to be a fixed intention to ignore the San Blas route entirely, and "pooh-pooh" it out of sight; they may knock it down, but it will come up again; they may throw cold water on it, but it will come out of the fire brighter than ever; they may build the Nicaragua Canal, but the San Blas will be built too, and then it will require no very wise man to tell which will be the one used. In the papers and estimates made out to compare the different routes, I see nothing said of comparative cost of repairs and maintenance; leaving the Panama route out as an absurdity, the lengths of the San Blas and the Nicaragua are as 1 to 6, but when it is considered that one is a sea-level canal, with good harbours and without locks, cut for a large part of its length through solid rock, the southern half in an open "savanna" country, the whole easily made safe from the ravages of floods and drains; while the other route is on and parallel to a tremendous drain, where floods occur that may and probably would sweep the whole works to destruction in a few hours; where earthquakes may and probably would twist the locks so that the gates could be neither shut or opened; where side streams, with their floods, must cross the canal to get into the main drain; where the time of transit compared to the San Blas is as 5 to 1; where there are no good harbours at either *terminus*, and where one *terminus* is a notoriously unhealthy place. I think any careful and critical mind would put the ratio of conservation of the two routes not as 1 to 6, but as 1 to 20 or 30, or more.

A five-inch rain falling in twelve hours is a thing not unknown in the Nicaragua lake region; as the water-shed of the San Juan River is 12,500 square miles, a five-inch rain is represented by over 4,000

millions of tons of water, a greater part of which has to find its way to the sea by the San Juan river, and not take a great length of time either; it was undoubtedly after one of these great rainfalls that the San Juan River, rising above its banks, overflowed, and cut the Colorado River into the territory of Costa Rica. Those who are curious in the matter, might calculate the foot-pounds of energy or force developed by 4,000 millions of tons of water falling 107 feet, and its power for doing mischief.

Apparently the only objection to the San Blas route is its cost growing out of a long tunnel, and the inability to say what kind of material would be found in the tunnel. Let us examine this great bugbear, the tunnel, and compare it with other works.

The "Desaguadero" in Mexico, cut by the Spaniards, as a matter of precaution against floods, two hundred years ago, required about three times as many cubic yards of rock to be removed as would be required to cut a ship-tunnel 8 miles long, 180 feet high, and 80 feet wide. Now, if the Spaniards could do that two hundred years ago, should we, who have steam drills and wonderful explosive compounds, shrink in fright from a work of only one-third the size?

The St. Gothard Railway, now nearly completed in Switzerland, to connect the northern railway system of Europe with that of the South, is a work that involves immense difficulties. It has on its line forty-six tunnels, one of them at the summit being over nine and one-fourth miles long; one of them the engineer pointed out to me as being cut to secure the railway line from being buried by avalanches. Seven of these tunnels in complete circles of 1,000 metres diameter, are cut merely to get distance, and keep the gradient down to their fixed standard of 1 in 40 (132 feet per mile), and this tremendous work is being built for the very limited business of a railway. With this example staring us in the face, are we Americans, who boast ourselves of doing things with a bigger "auger" than our neighbours use, to turn tail and run away from a tunnel that would, if built, command the trade of the world, give us a grip on the trade of the whole Orient, allow us to manufacture all our own cotton and find a market for it in China, connect our Pacific possessions by a less expensive route than any railway can supply, consolidate our Union in stronger bonds, and lead in time to our becoming the most central and most powerful people in the world.

It has been objected to this tunnel, and reiterated by Mr. Menocal, that the rock found in it may be too soft, or of a character not fitted to support its sides and roof. This is all "moonshine." We know from mines and cuttings over all that country, and from surface rock that crops out everywhere, just what we may expect; there is but one material existing that we may be afraid of, and even that was successfully overcome in the Box-tunnel of the Great Western Railway of England—I mean quicksand, and that we know we will not find under the rocks of the Isthmus. Mr. Menocal thinks we have not the data by which we can calculate the cost of the San Blas Canal as fixed and clear as they have for the Nicaragua Canal. If they have not these data it is their fault; they should have got them; but I contend that we have all the data required, and more reliable than any data ever can be, on a line parallel to and close to a line of drainage, that Domine Sampson might call with truth, "prodigious:" we have the length of the whole route: we know what is tunnel and what open cutting; we know to a certainty that we can turn off all the streams and the one river, the Chepo or Bayano, and render them harmless to do evil. We know that we have good harbours on this route; we know that we have rock to contend with in fixed quantities, and by estimating it as granite, we know that the estimated cost cannot be far wrong. It has been intimated that earthquakes might make a tunnel unsafe and dangerous; in answer, I would say that we have sixty-two tunnels on the line of the Oroya Railway in Peru, that many of them are completed and have been run through for years, and to this day I have never heard of any injury done to a tunnel on that line from earthquakes, which are much more frequent there than on the San Blas route.

We need not be afraid of striking a great vein of gold or silver, for in a case of that kind, unless the tunnelers become demoralized, such a vein might be coaxed into paying all or a part of the expense of the tunnel. This is not a speculation, unprecedented in facts, for my old friend, Genl. O'Brien, when forced by San Martin, the Liberator, to accept the Salcedo mine, in Peru (the richest mine at that time that had ever been worked), for his services in the wars of independence in Buenos Ayres, Chile, and Peru, struck a rich vein of silver in cutting an adit level from Lake Titicaca that paid all the expenses of cutting the tunnel for a long time. If some of the Bonanza kings of California could be induced to

suspect another Comstock Lode on the line of the San Blas tunnel, they would cut the tunnel for the fun of the thing, and thank you for the chance. But if we throw out the silver speculation and return to the "hard-pan" of a hard-hearted contractor's prices we may have the following estimate to stare in the face :—

14 millions of cubic yards of rock in the tunnel above the sea level (the tunnel being 8 miles long, 150 feet high above the sea, and 80 feet wide), at say, \$3 per cubic yard,	\$42,000,000
4 millions of cubic yards of work in tunnel below the level of the sea (this part being 80 feet wide and 30 feet deep), at say, \$8 per cubic yard,	32,000,000
22 miles of open (earth and rock cutting) canal at the same price Mr. Menocal estimates his line from Del Medio to Brito, where it is all rock, at, say, one million per mile,	22,000,000
Diversion of the Rio Bayano, say six times as much as Mr. Menocal estimates for the diversion of the San Carlos, $\$283,578 \times 6$,	1,700,000
2,400 acres of grubbing and clearing, at \$100 an acre, the same as Mr. Menocal estimates an acre at, this gives a width of 875 feet for 22 miles, say,	240,000
Diversion of other streams, all small ones, say,	1,000,000
Light-houses, piers, store-houses, buildings of all kinds, say,	1,000,000
Total, ..	\$109,940,000
Say,	110,000,000
Add for contingencies 25 per cent., ..	27,500,000
Grand Total, ..	\$187,500,000

The above estimate is considerably above the estimate of Mr. Menocal for the Nicaragua route, but I will here venture to predict that it is very much nearer the truth of what the Nicaragua Canal will cost, if ever built, than Mr. Menocal's estimate. We may as well stare the truth in the face now as at any other time; it is the most honest way.

The people of the United States have had too much to do at home to look with much enthusiasm on works in distant countries or study with care the vast interests wrapped up in foreign trade; but the day is fast coming when they will be forced to know and value this matter, and then they will cut a canal through the Isthmus on the shortest route that can be found, no matter if there is a Nicaragua Canal or not. I am

glad to find that all of the old canal engineers that have ever visited the Isthmus, and made a study of this problem, join me in the opinion that the San Blas route is the best for a sea-level canal, and the proper one to construct. And Mr. Kelley, who has spent his life and a fortune in surveys and study of this matter, and who has as clear an understanding of the whole subject as any man living, also most enthusiastically gives his adherence and support to that route as the only one that can satisfy the coming demands of trade, which is doubling up on us much faster than any one but those who study statistics could imagine.

As I feel convinced that the indirect benefit to the nation to be reaped from this canal is far greater than any direct benefit to any company, I would propose that the canal be cut, not on the line that is found to be the cheapest in first cost, but on the line that can be worked the easiest and quickest, and in the most reliable manner as regards line, level, repairs, and freedom from accident, even if it cost double the amount of the cheap and unreliable line. And in view of this end, I would, if I were the Government, offer to any company that would undertake this great enterprise, to give them one-half of the entire cost, and let them enjoy the rights, immunities, and profits of the whole thing, free of interest, for one hundred years; but reserving to the Government the right to take the whole at the end of one hundred years by paying one-half the original cost. It may not be out of place in this discussion to bring to the notice of the people of this day the prophetic writings of some who have preceded our time. Gouverneur Morris, the statesman, in a long letter, written in January 1801, to John Parish, in Europe, says :

"As yet, my friend, we only crawl along the outer shell of our country. The interior excels the part we inhabit in soil, in climate, in everything. The proudest empire in Europe is but a bauble compared with what America will be, must be, in the course of two centuries, perhaps in one."

Robert Stephenson, the engineer, in writing to his brother-in-law (in London), when he was here in 1853, after speaking in the most enthusiastic terms of the progress and development of this country, says :

"Considering these circumstances, and looking at the boundless rich territories which are being opened and extended daily, I confess I am entirely at a loss to figure to myself the part which the United States

are destined to play in the world's theatre; their influence must daily increase, and when her inhabitants reach the coast of the Pacific their power must become predominant as a commercial nation." * * *

"Coal which has hitherto given England her commercial superiority, is possessed by the States in almost incredible quantities; it has as yet scarcely been touched, because other sources of profit have presented themselves; but the day must arrive when, like England, the Americans will become a powerful manufacturing nation. If this be anything like the truth, how strangely must the relations between the civilized nations of the earth be changed—and then arises the question, so full of interest to an Englishman: Will England still maintain a good position in the struggle of countries, or will she, like other empires that have dropped into the past, begin to decline, and in her infirmity, like an aged parent, be obliged to look to her trans-Atlantic children for aid and support?"

We are fast arriving at the point predicted by Mr. Stephenson. We must have outlets for our products. In what direction can we turn for a market for our manufactured goods but to the shores washed by the Pacific and the islands of that great ocean? China and Japan, Australia and New Zealand, invite us to a close intimacy. The Spanish republics of the South American West coast offer us many tempting chances for trade enjoyed at present almost solely by England. The Orient and Occident of our own country wish to shake hands over a cheaper route of transport than any railway can supply. Let us mingle the waters of the Atlantic with those of the Pacific on the best, shortest, and most reliable route that Nature has furnished, or let us leave it entirely undone, for others of greater courage to accomplish.

I find in some of the discussions on this important problem that the San Blas route is called impracticable, but in no case is an attempt made to demonstrate the impracticability. Surely it cannot be because it is so short, so straight, so free from floods, locks, dams, and aqueducts, or can it be that it is rejected on account of its having good harbours, and in a healthy region, free from swamps and lagoons. What can the claim of impracticability spring out of that blinds the Nicaragua promoters to the many points of merit of the San Blas route unsurpassed and unsurpassable by any other route; there is but one point on this route that the objectors can fix their harpoons into, with any shadow of a chance of bringing it home to the minds of men as a dead fish. It is the tunnel; that is the bugbear, the

stumbling block, that narrow minds and unprofessional minds cannot climb over, creep under, or swallow whole. I am inclined to think that the tunnel is one of the best features of the whole route; it will cost, no doubt, a rousing big sum, but the amount will be a mere bagatelle to its value and importance, and when built it will be the surest and safest portion of the whole route; it will be through solid rock, and remain for ever intact, requiring little or no repairs. The heading, a very insignificant part of the whole, would cost as much per cubic yard as any railway tunnel, but the balance down to the sea-water level could, in that region, be done cheaper and quicker than an open cut of the same dimensions, where the average haul was the same, for the reasons that the men can work continuously without being driven off by the great rains that are so common on the Isthmus, and they can work, as in all tunnels, night and day. This tunnel can be cut cheaper per cubic yard than any railway tunnel could be in the same region, and for the reasons that the great width of the tunnel allows the men abundance of room to work in, and use all classes of labor-saving machinery; the force of the explosive compounds can be utilized to a greater extent, as there is more room for expansion. Any contractor can afford, and will afford, to take such an immense work at much less per cubic yard than he would think of asking for a small tunnel, such as are built for railways, for he can afford to procure and use the most perfect, extensive and efficient machinery ever used on any tunnel ever cut. I was shown at the St. Gothard Tunnel steam drills that by slow motion and high pressures would walk into granite as a knife would into cheese; there was nothing used on the Mount Cenis Tunnel to approach them in efficiency. I was shown air compressors that kept their great reservoirs night and day under pressures of 110 pounds to the square inch, and without difficulty; it was with difficulty and uncertainty that the air compressors of the Mount Cenis Tunnel could keep the pressure up to 60 pounds to the square inch. We are clearly a progressive race, and it would be a wise brain that could predict with certainty what advance may be made by some live Yankee in tunneling machinery when we come to cut a ship tunnel. I have copies of the entire maps and profiles of the St. Gothard Railway, and I have no hesitation in saying that they show the most complete and perfect surveys yet made for any public work ever attempted by man. There were 400 engineers and their assistants employed on these surveys, many of

them highly educated and experienced men; their estimate of the cost of this great work, 109 miles long, was 187,000,000 of francs; that was the sum placed before the public at the time the International treaty (of Germany, Italy and Switzerland) was signed, and a company formed to build the works, but they were only started when it was discovered, that, as usual, the works had been under-estimated, and the cost was going to be swelled to 289,000,000 of francs, showing an error in the first estimate of 102,000,000 of francs. Where was this tremendous error made—in the great tunnel? No, for the estimate of that was 70,000,000 of francs. Monsieur Favre took the contract to build it at 50,000,000 francs, and if he had lived would have completed it in the coming year, without asking favors or assistance. There is an inference to be drawn from this statement of amounts, regarding estimates and costs of work in tunnels, and general work, which the intelligent reader will quickly see. Mr. Menocal estimates his great canal, 181½ miles long, at \$66,000,000; the St. Gothard Railway is to cost, for 109 miles, about \$58,000,000; now, if the canal costs only as much per mile as this railway, it will cost about \$97,000,000. The railway costs about \$582,000 a mile, while Mr. Menocal estimates this great canal, with artificial harbours, great locks, but not large enough for great ships, great excavations of rock under water, great aqueducts and great dams, all liable to be swept out by the first great flood, and great embankments (sustaining a hydraulic head of 26 to 30 feet) perched upon side hills, all of which may be washed out through the never ending labors of rats and roots in boring holes, all complete and ready to accommodate the trade of the world, at \$346,000 a mile.

It may be claimed that the rock excavation under sea-water level is the impracticable point. If so, are not the excavations under water on the Nicaragua route equally or more impracticable. Let us stare some of the facts of this matter in the face. Nearly all of the excavation of rock under sea level on the San Blas route will be in still water, not affected by currents or winds or tide, while the same class of excavations on the Nicaragua route, in the beds of the San Juan and Rio del Medio, and in the bed of the lake, will be severely affected by currents in the river and waves and winds in the lake. To excavate rock in a swift current, such as is to be seen in the San Juan, is a species of fun engineers do not much covet. General Newton preferred to burrow

under rather than attack the current at Hell Gate. Then, as to the work to be done out in the lake, I have an impression that this feature has been very much under-estimated. Suppose we subject this to a few figures, from known data, at one point. It is to be regretted that there is no good hydrographic survey of this lake, so we must be content with such data as we can pick up. The history of this lake and river show that, some years ago, a certain Captain Sheppard took his schooner from the gulf up into the lake during a flood. He did this with great labor, by taking off his false keel and taking out his cargo, reducing the draft to about three feet. Once in the lake, he put on the keel, and, with the vessel loaded—drawing seven feet—he could not, in the dry season, get within two miles of San Carlos, at the upper end of the San Juan River. Now, taking this little piece of history to calculate by, and knowing the material to be rock, I make it that a canal only 100 feet wide (I call it 100 feet wide, not because that is enough, by three or four times, for the passage of a ship subject to the buffetings of winds and waves in a great lake and the canal out of sight, but because 100 feet is sufficient for the demonstration I wish to make), cut from the mouth of the river out into the lake, so as to have 28 feet of water all the way to deep water, will call for the excavation of about 1,100,000 cubic yards, which, at \$8 a yard, will come to \$8,800,000; but, for the sake of being generous and accommodating, suppose we call it the half of the above sum, and then it is six times as much as Mr. Menocal estimates as the cost of all the work to be done in the lake division, including mud and gravel, which, it is admitted, has to be dredged, and also the rock under water at the western end. Heaven only knows how much is required to be cut for a channel to get into the mouth of the Rio del Medio.

Let us return for a moment to the San Blas route, and take a fair, square look at the rock to be excavated there below the sea level. In the tunnel, where the great mass will be found, it may be dry, and it may not. Take it on the side of the "may not," and allow it to be as wet as ever was seen, is it supposable that any engineer in his senses, with but a smattering knowledge of hydrostatics, would attack it under water, when he can so easily build bulkheads, pump out the water, and work out the rock just as he did above the level of the sea. With this system of working kept fairly in view, I have a fancy that any intelligent man can see that this rock in the tunnel will come out more quickly and cheaply

than will the rock in the bed of the lake, when the winds and the waves will be playing "hob" with the drilling machinery, and at times driving the men from their work. But suppose the work finished—who can estimate the distress of mind of a captain when he finds his ship in a great lake with a wave-swell of 8 to 10 feet and only 2 feet of water under his keel; and that, too, only in a canal out of sight.

In my estimate of cost I dealt in big figures, and estimated for a depth of 30 feet of water. To bring this to the 26 feet of Mr. Menocal's section, there should be deducted over \$4,000,000. Then again the tunnel, on more accurate surveys being made, may be reduced to six miles instead of eight. This would reduce my estimate again by \$15,000,000, and then the 25 per cent. for contingencies would come down some \$5,000,000, making in all some \$24,000,000 of reductions. But I prefer to let it stand as I had it, at \$137,500,000, and time will show who comes nearest to the truth, for it is in my eyes a sure thing that a great world's canal will some day be cut on the San Blas route.

As the transit of any of these canals will have to be suspended during the night, and as the San Blas route is so short that it can be navigated from end to end in ten hours, or less, and as one passing place (at south end of tunnel) only is required, the whole of the rest of the canal can be made, and should be made, much narrower than would be allowable and required on the Nicaragua route, where passing places must be frequent and provided between all the locks.

As sailing vessels are destined to form a great feature in the traffic of this Isthmus Canal—a feature that the Suez Canal is entirely deprived of—I beg to refute the claim made by the Nicaragua projectors, that the Bay of Panama is difficult to get in or out of on account of calms. I have been at Panama for weeks—I have been a guest on board of a United States war vessel for two weeks in that bay—and I never saw a day when a vessel was detained there, or prevented from coming in by either calms or storms.

New Yorkers would feel very indignant if told that their port should be shunned on account of its being difficult to get in or out of, and yet, I suppose, they all know that sailing vessels have often been for days outside, afraid to come in, and for days, in the lower bay, afraid to go out, during times of storm and fog—two hygrometric and meteorological features never met with in Panama Bay. Let us place the "calm" claim

alongside of the "impracticable" claim, and send them both to the safe keeping of croakers. Intelligent men of this age are not going to take much stock in those two articles of Nicaraguan faith.

It getting from our shores to China and Japan, the great objective points, we as a growing commercial nation should look with much respect and admiration on the pacific character of the Pacific Ocean. The Spaniards of old used to say that all a "skipper" had to do on leaving Panama for the Phillippine Islands was to set his course, tie his rudder fast, go to sleep, and not wake up until he reached the end of his voyage. Ships going from Panama to China can take a trade wind going and a trade wind returning. When the canal is cut, and we have a new highway to the East, this feature will play an important part in assisting us to the largest share of the trade and traffic of the Orientals—a trade which for centuries heaped wealth into the coffers of the Greeks the Jews, and the Armenians of the Mediterranean—a trade that England seized and grew her wealth and power out of, when Vasco de Gama showed her a new way to the East by the Cape of Good Hope, four hundred years ago—a trade that is destined to fall into our hands and give us wealth and power such as no nation ever held, as soon as we can muster courage enough to cut an Isthmus Canal on the shortest route that can be found, and throw it open for all the world to enjoy as best they may.

It may not be inopportune to mention in connection with this discussion that a late commanding officer of the United States Navy, now living in Washington—a gentleman well acquainted with Nicaragua, Panama, and the Pacific Ocean—once said to me: "I should be very loath to allow any ship I commanded to be run in a canal and locked up a hundred feet above the ocean. I should be afraid of never getting down again."

In connection with the risks run by placing a big body of water on the side-hill slopes of a river valley (in a region of great rains) in a prism made of cuts and embankments, crossing spurs of hills and ravines, and also to show the fallibility of man's estimates, I beg to mention a little incident that occurred on the line of the Oroya Railway in Peru, in the Valley of the Rimac. The final location had been made, and for some time the construction of this railway had been going on in a region almost rainless. At a point in the valley where the line crossed the mouth of a ravine we had left an opening to be filled by a bridge of 100

feet span. At the head of this ravine some poor *peons* had been cultivating the soil on the top and side of the mountain by bringing the water of melted snow from other and higher mountains for irrigating the land, as water in many parts of Peru is valued like gold. The *peons*, with great labor, puddled and protected the edges of their "chacras" so as to prevent loss by waste. The water sunk into the soil, and permeated down deep through stratas of alluvium, gravel, clay, and loose rocks. This was close to and on the side hills leading down to the Valley of the Rimac. This gradual permeation of rock and gravel, clay and sand, with water had, no doubt, been going on for a long time. The water was trying to find its lowest level. The rocks and the earth were only waiting to be released from the bonds of cohesion that had held them on the mountain side for ages to show what attraction of gravitation could do. Day by day this insinuating element, water, was doing its work, in the dark and in the night. Ceaseless, unopposed, all powerful, it was cutting and severing the bonds of cohesion. The people in the valley in front of the ravine rested in quiet content. The *peons* of the mountain imagined no evil genius underlying their crops, but in a moment when no one suspected danger the whole mountain side started for a race to the valley. Five millions of cubic metres (about ten millions of tons) of rock and earth, gravel, mud, and water came rushing into the valley, crossed its whole width of 1,400 feet, surged up against the opposite side, rolled over and crushed out of sight all the houses in its annihilating course, and filled the valley with a dam 1,600 feet wide on the bottom and 108 feet deep. The average vertical fall of this vast body of earth was about 1,500 feet, and the horizontal movement over 5,000 feet. Surely water has power, and we are entitled to place it with its sister element, fire, as good servants but dreadful masters. Gouverneur Morris, the projector of the Erie Canal, proposed that it should be built without locks, and on a line that would give it a uniform descent per mile from Lake Erie to the Hudson River. What a magnificent idea. It was too magnificent for the time. A line of this kind would carry the canal to the south of Cayuga and Seneca Lakes. With fifteen millions of tons of surplus grain in the far West seeking a market on the Atlantic seaboard, it would soon make New York the imperial city of the world, if it could find its way by water lines, without one check or hindrance, from the great grain fields to the great city.

A canal built as Morris proposed would not have a greater descent per mile than is now existing in the Ganges Canal in India, which has a fall of fifteen inches to the mile, and is navigated in either direction with facility and certainty. I mention this canal and its gradient to show that even a guard-lock is not a necessity at the south end of the San Blas route to provide for the current that would be created in the canal at extremes of high and low tide of the Pacific, but a guard-lock there would be a convenience and an economy.

Since the above was set up, another number of the Transactions has come to hand, containing an account of the special meeting to welcome M. Ferdinand de Lesseps. M. Lesseps, it will be observed, states that he went out to examine the route selected at the Paris Conference, i. e., the Panama, but he is equally strong in his condemnation of either lift locks as on the Nicaraguan or Tehuantepec routes, or tunnels as on the San Blas route. I think, however, I shall not err in printing the Proceedings *in extenso*, and it therefore follows here. I may remark also that M. Lesseps' estimate is 120 million dollars, but little under the figure predicted by Mr. Evans.

Introduction by O. CHANUTE.

Vice-President O. Chanut was in the chair, and after calling the meeting to order, said :

This is a special adjourned meeting of the American Society of Civil Engineers, held for the purpose of welcoming to the United States the distinguished Engineers who have just arrived from Central America, and of hearing what they wish to say concerning the American Inter-Oceanic Canal. We shall first be addressed by M. de Lesseps. As, much to his regret, he does not speak English, his communication will be made in French, and, at his request, a synopsis of each portion of it will be made in English by Mr. N. Appleton. M. de Lesseps will also answer any questions which may be asked. After he has terminated, we shall have an account of the works proposed, by Mr. J. Dirks, Chief Engineer of the canal from Amsterdam to the sea.

The American Society of Civil Engineers has heretofore endeavoured to contribute its share toward the understanding of the subject of the Inter-Oceanic Canal, by gathering information concerning the various

routes, the plans proposed for the canal, their probable cost, and the commercial bearings of the project.

This it has done, not with a view to revising the plans of what is, after all, a private enterprise, nor to pass judgment upon them, for the Society commits itself, as a body, to no views, and neither for nor against any project, but rather to collect the data required, that its individual members might form an intelligent opinion concerning the merits and probable results of an important undertaking, in which the American public is to be invited to take a share.

Beginning in November last, with the reading of a paper upon "Inter-Oceanic Canal Projects," by Mr. Menocal, member of the Society, and one of the delegates to the Paris Congress, the discussion has been participated in by many prominent members of the Society, as well as by several gentlemen who promote particular routes, and we have been fully informed concerning the San Blas, the Nicaragua, and the Tehuantepec routes.

But little has yet been said in those discussions concerning the Panama route; it being generally felt, that pending the proposed revision of the location and of the plans for the canal, by the very able engineers who had the matter in charge, it was desirable, before any opinions were expressed, to await the announcement of the results.

We are now able to learn these results, as well as the facts and plans upon which they are based, in the most direct, certain, and satisfactory manner; for we have among us to-night, as a guest, the chief manager and promoter of the enterprise; a gentleman of world-wide fame, as the builder of the Suez Canal, who, having already accomplished labors which to other men would be the work of a lifetime, having connected in the face of the most strenuous difficulties, two great seas across the trackless sand of the desert, now proposes to perform the still greater feat of cleaving the American Isthmus asunder, to connect the two great oceans of the world. Gentlemen, I have the honor to introduce to you M. Ferdinand de Lesseps.

Discussion by M. FERDINAND DE LESSEPS.

Mr. President and Members of the American Society of Civil Engineers, Ladies and Gentlemen: I am very happy to be here this evening, not only because it gives me an opportunity to set forth my views on the great project which I have so much at heart, and which I think when

completed will be so great a blessing to mankind, but also at finding myself immediately upon my arrival in America, the much honored guest of this Society of Civil Engineers, before which, above all others, I consider it proper that I should first address myself. I am not an engineer by education, having been for so many years in the profession of a diplomatist, yet I am happy to be received as an engineer, and I am happy on that account as well as for the personal honors which have been paid me and the many opportunities afforded me for seeing in the short time I have already spent on shore what were to me most interesting and instructive illustrations of American engineering, skill and science.

I desire to begin at the beginning. In 1870, soon after the completion of the Suez Canal, and after that work had begun to be put into regular use, I began to think seriously upon the question of an inter-oceanic canal across the narrow land separating the two oceans in the Western Hemisphere. The first difficulty was the supposed difference in the levels of the two seas. An impression that there was such a difference had gone out and in many quarters was seriously believed, though for what reason I could not find out. Upon a careful examination it was discovered that this difference of sea-level was a myth, and that the only basis of the myth was the ebb and flow of the tide, which differed on the two sides of the Isthmus, but which would make no difficulty in the construction of a sea-level canal—for that from the first was the sort of a canal on which I had set my heart, and which I will build or abandon the project. I will not take up the various steps through which we passed in the consideration of this problem, for I can assure you that there were much study and many investigations during the years intervening between my first determination on the subject and the present time.

I determined not to occupy myself with political opinions, but from the moment I began the enterprise to devote myself to the practical part of the undertaking. I looked at the subject from a commercial view.

I am convinced and persuaded that the enterprise will be not only for the great advantage of commerce, affording an easy route to the Asian continent or India or Japan, but will produce results which will develop the shipping interests of the United States to the place they occupied twenty-five years ago.

I had the honor of the acquaintance of Senator Sumner when he visited France, and he gave me many valuable figures on the state of

American shipping at that time. He stated that the tonnage of American commerce at that time was about 5,500,000 tons. England at the same period had about 5,000,000 tons. All the commerce of the earth could have been divided into three sections, America owning one, England another, and all other nations together having an amount about equal to that possessed by each of these. Since that time America has fallen away as regards maritime commerce, and especially since the opening of the Suez Canal. Its commerce is very low, much more so than it should be for a people so great and powerful as the Americans. But I reflected that this was not to remain so; it cannot remain so with the Panama Canal open to encourage American shipping, as it certainly will do.

The Suez Canal has had the effect of changing the commerce of the whole world, and improved its shipping to an extent altogether unanticipated. It has caused the building of large steam vessels, which have supplanted the sailing ships. You will see that a similar metamorphosis will follow the opening of a Panama Canal. American shipping has fallen off since the war, and the mercantile marine, I am informed, is now in a deplorable condition. The opening of such a canal would give a fresh impetus to the building of American shipping and assist you in regaining the position that you have lost. To-day I say to the American people, prepare yourselves in six or seven years to see your commerce extended from the North Pole to the South. When you shall have comprehended the importance of the canal, you will see that your commerce will be benefited according to your large population, and that no other country will have pre-eminence over you when the canal is opened. I work not for selfish motives, but for the interests of humanity. Should you not, therefore, concur in the project as other countries have done?

I will compare the Suez Canal with that proposed at Panama, and show, as I hope, that the one across the Isthmus would be an easier matter than that joining the Red Sea and the Mediterranean. In the first place, there was no precedent for the Suez Canal in modern times. The ground had been a battlefield of nations since the commencement of historic times. In the time of the Pharaohs, there were fresh water canals in Egypt, in the construction of which the natural watercourses were often utilized.

The first canal proposed for crossing the Isthmus of Suez was in the time of Phillip II. He at first acquiesced in the idea, but being a very

jealous monarch, and afraid that other nations might profit by the canal, he afterwards insisted that the project should be abandoned. An edict was issued declaring all men impious who should propose such a canal. Even if they spoke about it they were to be put to death. This was his order, and as they knew he had the power to carry it out, the subject of the canal was quickly dropped. I hope the example of Philip II. will not be followed in America. It would be very inconvenient for some of us to have such an edict in force.

Since the time of Columbus there have not been wanting those who thought that the American Isthmus could be traversed. It was first thought feasible by using the natural ports, lakes and rivers. The regular study of the question of the inter-oceanic canal began in 1875. There was then at Paris a universal geographical congress, and there I talked with Professor Nourse, from your Government offices in Washington, and I discovered how much interest was felt in the canal in America. I was charged to preside over the inter-oceanic section, and I obtained from Washington all the plans of proposed routes. Of all countries the most concerned was America. Some said that America did not want the canal, but I replied, "You deceive yourselves. America wants to develop commerce in the entire world." To prove that America wanted the canal, perhaps I exaggerated a little, but I said that she had spent already about \$1,000,000 in exploration and in the attempts to find out how to start right in this great work. I said at the Conference that America having built a line of railroad across the Isthmus, it was a good argument in favor of crossing it at that point. The American engineers chose this route thirty years ago, and built their railroad there.

A new congress was proposed, to which that special question of the canal was to be referred. I wrote a number of letters to leading engineers in Europe and America, inviting them to come to Paris to discuss the scheme. Every one came at his own expense, and the first engineers of Europe were there. Over one hundred persons were present, the élite of the entire engineering world. We were divided up into sections, one on engineering, one on navigation, one on statistics, one on the movement of commerce, and one on finances. Each committee commenced its work without wasting any time. I said we should go to work *à l'Américaine*. "How is that?" they asked. "Quickly," I said. And after what I saw yesterday, I can say that I never before knew fully

what it was to speak of anything being a *l'Americaine*. Now I know what it is when I see your bold street elevated road and your magnificent bridge and your other works of freedom in science.

At it we went for fifteen days, night and day. All our deliberations were afterward printed. I remember that in connection with the Congress something was said to the effect that the American delegation was not treated with due consideration. This was an erroneous idea. Admiral Ammen was made First Vice-President. I do not think any discussion was started that the Americans were not in courtesy first called upon to speak upon it, and when it came to the final vote, every man could vote as he pleased, and also give in writing his reasons for the vote. There was not only no disfavor shown the Americans, but I was even charged with showing partiality to them, and this charge will be found in the printed report of the proceedings. At the final vote, 78 voted for the Panama route and 8 against, 12 declining to vote. I did not expect until the last day to occupy the place I now do at the head of this gigantic work, but when I heard the exclamations of the Congress, and saw there before me, as I see it now, the face of my wife, I felt that I ought to put myself at the head of this work, and the completion of the circumnavigation of the globe.

I thought, moreover, I had not the right, after having gone so far, to refuse to see the work through. It would have been cowardice not to continue, so I advanced in spite of the opinion of Mme. de Lesseps. It has brought now the pleasure of a visit to America, and the enjoyment of the hospitalities which are now showering upon me, and which I should not otherwise have enjoyed.

The first thing after this was to get the concessions from the Compagnie Civile, which that body had secured from the State of Colombia. My plan was to offer the company \$1,000,000 in cash when the subscription for our undertaking should be taken up, and \$1,000,000 in the stock of the new company. This new company has not succeeded, partly on account of the opposition of the press, and the press is a great power and deserves to direct public opinion when it is managed by honest men. The subscription was not a success, and I paid back the money to all who had subscribed. Thereupon some of my friends came together, and placed \$400,000 in my hands to enable me to verify the surveys, and to pay the deposit required by the Colombian Government. I could not

have done this with my own means. I am not ashamed to say that I have no fortune. I have passed twenty years in diplomacy and thirty years in engineering, but I did not profit by any of the enterprises which I began. It is not my trade; I make it a principle not to gain anything from others. I have only the shares which I pay for myself. Those who invested their money in the enterprise have taken a great risk and have a fair right to the fruits of success. Now my work has commenced of executing the enterprise. It is a work of the entire world, not only for other nations, but especially for America.

Let us talk of the technical part. Determined to make a verification of former surveys upon which I had based my scheme, I repaired to Panamá with a party of ten well-known engineers. The expedition to the country has been safely accomplished, notwithstanding the dangers forboded to us. Much has been said against the climate of Panamá; but we did not suffer from it at all. The climate of Suez is infinitely worse. The heat at Panamá is from 23° to 33° Centigrade; at Suez 30° to 35°. We all came back in safety. The country was not dangerous at all, and was much more favorable to such an undertaking than that surrounding the Suez Canal, which I will now tell you of. The most celebrated engineers of France and England did not expect such a great success. I was treated as a fool because I simply desired to cut away the earth, whereas they had expected I would make a canal with the assistance of the Nile. I took engineers there and we occupied the territory. There was no water near, no houses, and it was nothing but a great plain of sand, containing nothing that could be of use to us. We used camels, and our laborers were divided in companies, some going in search of water while the others worked. There are no rains at Suez; it never rains there. The difficulties were almost insurmountable. There were battles with workmen, water had to be carried sixty leagues, we had fierce storms to encounter, and for the first two or three years we scarcely got a foothold. The sand did not frighten me as it did the public. It did not take much trouble to remove it, of course, and most of it was done by hand, before we had machines. But the taking out of clay was a more serious undertaking; in some respects it was more difficult to deal with than stone, because it could not be blasted or removed in blocks. Suez was far worse than Panamá can be. We remember how we were told most solemnly that Suez could not be built, but

we went, I shall say again, *a l' Americains*, and did it, and now we propose to do it again. I have shown you the difficulties at Suez; at Panama there are no such difficulties.

Now (referring to a model in relief, of the proposed line of the Panama Canal), I will briefly sketch the route for the canal: It begins on the Atlantic side, at Colon (Aspinwall), and joins the valley of the River Chagres, a little south of the bay of Limon. The River Chagres however, does not empty into the Bay of Limon, but into the sea at the old town of Chagres. The canal follows the valley of this river to a point near Matachin, where the river has a sharp turn towards the north-east, and runs between two mountains. Here the canal leaves this valley, and it is proposed to construct a dam between these two mountains to provide for the storage of the flood waters of the river. This dam will be forty metres in height, and will retain about one thousand millions cubic metres of water. There are at least three dams in the world, which are of equal magnitude with this, and which have stood for many years; one in Spain is higher, and has endured three centuries.

The canal, leaving the valley of the Chagres, cuts through the mountains at Culebra, where the extreme depth of cutting will be about 270 feet, almost exactly the same as that of the towers of your great Brooklyn bridge, which you have just kindly shown us. Thence the canal will follow the valley of the Rio Grande to the Pacific, which it enters near the City of Panama.

Another advantage possessed by the Isthmus of Panama over that of Suez is its fertility, being a perfect paradise; there is no botanical garden in the world which could surpass it in beauty. The stations on the American railroad are surrounded by villages, and there is plenty of game in the mountains. I leave to the engineers with me the explanation of the details of the proposed plan, who will report as to the country which they have passed through, and after they have finished I will be at the disposal of the public to respond to all questions which any one may choose to ask.

Now, I beg to present this model to the Society of Civil Engineers, and to thank them for this opportunity of addressing you.

Discussion by J. DIRKS.*

In the first place I beg to call your attention to the fact that neither

* Chief Engineer of the Canal from Amsterdam to the Sea.

the English nor the French is my native language. For this reason I invoke your kindness in overlooking any mistake as regards pronunciation; also grammatical errors. M. de Lesseps, the great mind who pulled down the Suez barrier, and therefore deserved, as well as earned, the thanks of mankind in general—came to America with the object of removing a second barrier, in joining together both oceans by a great ship canal through the American Isthmus. Allow me, ladies and gentlemen, to explain, in a few words, why M. de Lesseps deemed it convenient to invite me to join, not alone the Paris Congress of May last, but the scientific and technical survey of the canal line between Colon (Aspinwall) and Panama, which took place during the last few weeks. I have the advantage of being the engineer of the ship canal going from Amsterdam to the sea, which canal is fully described by your esteemed countryman, General Barnard, and was visited as well by himself as by other engineers of this great country, among them Captain Eads, the renowned builder of the St. Louis Bridge and of the wonderful works at the mouth of the Mississippi. When the general plan of the Amsterdam Canal was proposed, about 1860, only very few engineers believed in its feasibility, and the majority of scientific men were of opinion that a sea harbour in the shifting sands of the broad and shallow beach at the North Sea, as well as the dredging of a canal in the very soft mud of the lake through which it ran, were to be considered as quite impossible. Belonging to the small minority who were convinced that the Amsterdam Canal could be made and would fully answer the purpose, I was charged with the execution of the whole, in conjunction with Sir John Hawkshaw, from London, who acted as consulting engineer.

It is a great satisfaction to me that the Amsterdam Canal has been constructed; that the dark forebodings of a large majority never were realized; that the canal, at a cost of about \$16,000,000, is a complete success, and that the largest vessels, even to a draught of twenty-four feet, easily enter and leave the new North Sea Harbour and get to Amsterdam within four or five hours. If not for the results of this proportionally smaller, but nevertheless very important scheme, M. de Lesseps would very likely never have known even my name. I have to thank him here for his kind opinion regarding the little experience in canal matters that I may have got, and I beg to state at the same time, as recorded above, that I was not alone in my quality of acting chief engineer, but that the

great mind of my friend, John Hawkshaw, was there also, in order to avoid or to put aside many difficulties of planning and construction. As regards the technical possibility of a level ship canal between both oceans at Panama, I am happy to say again what I told a few days ago to some very competent men, namely, that I would like to write down my very favorable opinion in very large characters and put at stake my reputation as an engineer that the difficulties of this enormous work will be not greater—perhaps even less important—than those of the Suez Canal and of so many other great works completed with full success in America and in Europe. I want to state that the making of a deep cutting is just as possible at Panama as in the United States; that the blowing up of rocks may be done there even with greater facility than at Hell Gate, near this city, and, finally, that the only serious technical question to be solved is that of the floods of the River Chagres, through the alluvial and present bed of which a great part of the ship canal will have to be led. But even that difficulty can be surmounted. The result of the studies of Colonel Totten and Mr. Danzats, who went into the question with the utmost care, was set forth in the international report recently published, and known, as I presume, to the members of this scientific body. I may therefore confine myself to the renewed expression of my heartfelt thanks to the chairman and the members of the American Society of Civil Engineers, as well as to many other citizens of this great city. They show their regards and kind sympathy not only for the engineer but also for the Dutchman. They talk feelingly about the old ties between my country and the United States. The same old blood is running through the veins of many on both sides of the Atlantic, and what happened in past times may lead toward what may occur in the future, the relations between both peoples and the other nations will be progressing for ever, and each barrier pulled down on the broad way of commerce and industry will largely contribute toward such a blessed prospect.

O. CHANUTE.—M. de Lesseps is now prepared to answer questions, and I will begin by asking him, what are the estimates of the probable cost of the undertaking, and the probable returns?

M. DE LESSEPS.—One hundred and sixty-eight millions of dollars. Of this \$20,000,000 are for the large dam to keep the waters of the River Chagres in. It would not be necessary to have the work entirely completed before vessels could be sent through. I am satisfied, too, that the

final operations will show a considerable reduction. This is the reason that induces me to fix the capital at 600,000,000f. or \$120,000,000. But should my hopes in this direction not be fulfilled, the difference necessary to make up the estimate can be supplied by bonds or otherwise.

According to the returns of the Congress at Paris, it was calculated by M. Levasseur, the Chairman of the Committee on Statistics, that 6,000,000 tons would pass through the canal in a year, and that within ten years they would rise to 7,250,000. At Suez the tariff was 10 francs or \$2 per ton, but at Panama it could be raised to \$3, which would give a gross yearly revenue of \$18,000,000, which would be a very large return for a capital of \$200,000,000, which is much more than the canal is estimated to cost, including the running expenses and the interest on the money. And as this tonnage is greater than that which was estimated to pass through the Suez Canal, the canal on this continent would be a better investment than the other, and the stock and bonds of the Suez Canal are very much above par.

O. CHANUTE.—What proportion of the necessary capital will be raised in Europe, and how much do you propose to raise in this country?

M. DE LESSEPS.—The original capital will be \$120,000,000. One-quarter has to be paid up before a company can be formed under the French law. One-half of the capital stock will be allotted to the United States, and the other half to Europe. But in case it is not taken up by the United States I will try and have the sixty millions taken up in some other way. But I wish to have it understood that one-half the stock may be subscribed for in the United States, as the United States have an interest in the enterprise equal to all the rest of the world put together.

HORATIO ALLEN.—Past President of the Society :—I would like to ask a question, so that we may have a little clearer conception of the subject. I understand that the length of the canal from ocean to ocean will be forty-five miles; that a certain portion of that canal will be a deep cut, and that a certain other portion will be ordinary canal work. I would like to ask how many miles are to be cut through, and how many will be a deep cut?

V. DAUZATS.—The deep cutting extends for about six and a half or seven miles. The deepest excavation will be about ninety metres; and for this distance of seven miles the cutting may average about 180 feet. In other parts of the canal the cutting will not be of very great depth.

HORATIO ALLEN.—Is the deep cutting entirely in rock ?

V. DAUZATS.—Not entirely in the rock. There is earth over the rock. Col. Totten thinks that the earth may be twenty feet in depth, but in order to be safe the estimate was based on a depth of earth of twelve feet and the remainder rock.

Q. A. GILLMORE.—Will you give some details as to the proposed dam for the Chagres River ?

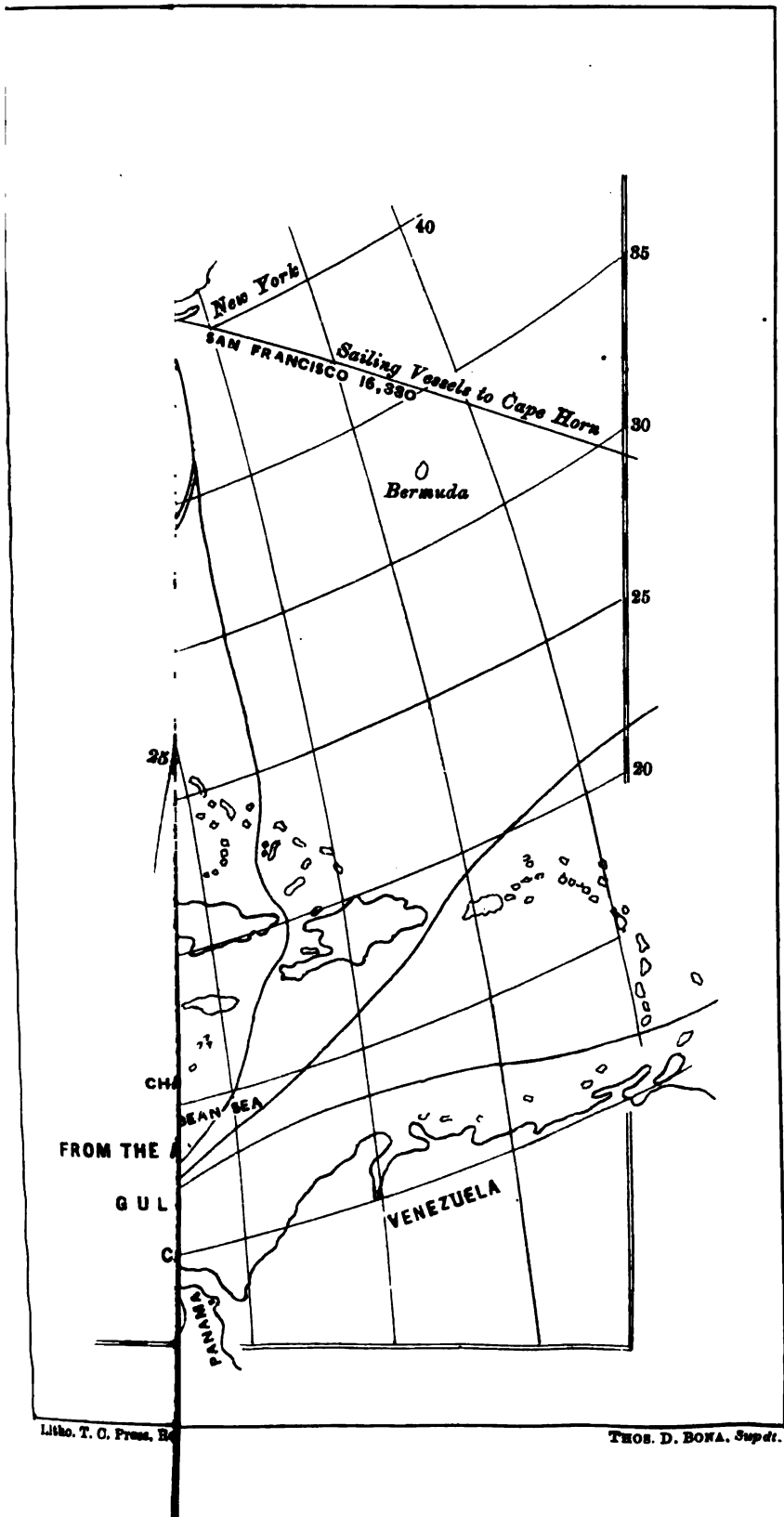
J. DIRKS.—The height will be 40 metres and the length 1,600 metres. It will form a reservoir capable of holding more water than the greatest flood known on the river. Before a second flood arrives the reservoir could be emptied by the main and the secondary canals. The dam can be sufficiently well built to make it perfectly safe.

ASHBEL WELCH.—Why go to the enormous expense of making a sea level canal across the Isthmus when a canal with two or three locks on each side of the deep cut could be made so much more cheaply ?

M. DE LESSEPS.—If the Commission of Engineers which had gone down to Panama had reported in favor of a canal with locks I should have put on my hat and left the whole project and would have had nothing to do with it. That plan may do for small ships, but when we have vessels now afloat 500 feet long and others on the stocks 600 feet long, it is impossible to say for what you would have to build the locks. Single locks would be slow, and double locks though quicker would be very expensive and require constant repairs. At Nicaragua they intended the use of locks, and with the earthquakes which prevail there the repairs would be ruinously expensive, and even at Panama, where earthquakes do not exist, they would be fatal by reason of the loss of time. I would not have anything to do with a locked canal except for little ships. It is not the proper idea for a grand inter-oceanic canal.

C. BUTLER asked why the San Blas route has not been examined.

M. DE LESSEPS.—The object of the Commission was to examine the line accepted by the International Congress ; but in reference to the route referred to by the gentleman, I would say, that although the port on the Atlantic side is very good, that on the Pacific side is not. This line would make necessary a tunnel of, say, seven miles in length, and as the Commission had already rejected a route in which there would be a tunnel of three or four miles, why adopt one having a tunnel so much greater in length ?



No. CCCXXIX.

JAMES CLEMINSON'S "FLEXIBLE WHEEL-BASE" OR
RADIATING AXLES.

[*Vide* Plate].

As carriages are now being fitted on this principle on the Scinde, Punjab and Delhi Railway, the following extract from the *Engineer*, February 15th, 1878, may be interesting. The plan seems to have been extensively tried in England, America and the Continent of Europe, during the last three years, and to have met with very general approval, and to work practically perfectly up to curves of 70 feet radius.

It is not clear from the description or figures how "the central axle is at liberty to slide under the main frame" of the carriage, but this is a matter of detail. The main frame probably rests and slides on the corner plates shown on each minor axle frame, and the only other connection is the two swivel pins of the end frames.

"Though the desirability of using some arrangement of the under carriages of railway rolling stock, by which the axles would be free to depart from rigid parallelism when traversing curves, has been felt for many years, it is only recently that much has been done in this direction as regards passenger coaches in this country. Previously all the stock, and even now on most of our lines practically all was, and is, fitted with wheels whose axles are rigidly parallel, a condition which could not have been allowed to exist so long had it not been possible to obtain the requisite engine power and strength of the parts of the vehicles and permanent way which such a system of construction entails. On a straight line a vehicle with parallel axles may be considered to need very little guidance by the flanges or rails; the tendency of such a vehicle in motion is to pursue obstinately a straight course, and from

it is only caused to depart by side pressure on flanges and rails. The intensity of that pressure may be imagined when the amount of skidding on any curve is remembered. For instance, a train passing round 90° of a curve of, say, 10 chains radius, is actually *skidded* through not less than 60 or 70 feet; the actual amount of skidding depending to some extent upon the length of the vehicles. The Americans first endeavoured in a practical manner to remove this defect by the application of the bogie, but even that very useful invention only partly removes it, as each bogie is in itself a vehicle with parallel axles, but with a short wheel-base. It is only recently, however, that even a bogie has been much used in this country, though it has for several years been known that long carriages run much more steadily than those of the ordinary length, and the proportion of dead weight, or non-paying load, may be made to decrease with increase of length. Carriages of increased length have been built, most of them running on six wheels with parallel axles, a certain amount of transverse play being allowed in the central axle. Even with this, however, the position of the wheels on a sharp curve is as illustrated in diagram, *Fig. 4*, from which the tendency of the wheels to mount the rails, and the increased power necessary on a curve as compared with a straight line, to pull such a carriage along, may be estimated. By the use of the bogie the strongest objections to long carriages have been overcome, but others have been imported by which the object of using long carriages has been partly defeated. The bogie car being supported only at or near the ends, its motion is little better than an ordinary short carriage, while the distance between the supports involves the use of very strong and heavy framing, and the bogies of themselves are of such weight that the paying proportion of the load, instead of increasing with the increased length, has in most instances decreased. The parallel axles of the bogies have, moreover, the objections which are attached to short carriages with such axles, so that, although it, as far as itself is concerned, permits the construction of long carriages, the grinding and waste of power on curves is as great as with ordinary short carriages, for the direction of pull of the long carriage on a curve causes a thrust on the inner rail at the foremost end and on the outer rail at the rear end.

“Our object here is to place before our readers a system of construction invented by Mr. James Cleminson, of Westminster, which overcomes

these difficulties in a satisfactory manner, its chief recommendation being that while securing other advantages it provides the means of passing round the sharpest curves with the axles always normal and radial thereto, whatever its radius, as shown in *Fig. 5*.

"This result is achieved by so attaching the axles to the carriages and to each other as to permit them to adapt themselves automatically and with perfect truth to the varying conformations of a railroad. This is effected as follows:—The axles, with their axle-boxes, guards, and springs, are mounted in frames BCD, *Figs. 1** and 2, separate from the main underframe E. The end frames B and D have central pivots H, around which they swivel freely, whilst the middle frame C is at liberty to slide transversely to the main underframe E through a range equal to the versed sine LM of an arc NLO, the chord of which equals the wheel-base NMO—see *Fig. 6*—and finally the frames are connected to each other by the articulated radiating gear IK. The action of the combination is simply thus—When a vehicle enters a curve, the middle axle and frame C move transversely through the versed sine of the wheel-base arc, and, in doing so, cause the end axles and frames B and D to swivel around their pivots H, so that all the axles assume positions of radii of the curve.

"There is, it will be noticed, nothing of a special nature, beyond the axle-frames, required in the application of the invention, either in building new carriages, or converting old stock, these frames entailing very little extra cost, for as the main underframe E is relieved of the strains ordinarily due to curves, it is said that it may be reduced in strength to such an extent as to compensate for the cost of the axle-frames. All standard fittings, such as axle-boxes, guards, and bearing springs, are retained without alteration.

"It will be seen that the system permits the construction of vehicles of any length, and secures the unattained objects of the bogie with the advantage of support throughout the length of the carriage. In very long carriages, say 80 feet, eight wheels would be employed, with a modification of the arrangement illustrated.

"The carriage illustrated by *Fig. 1** is the new Royal Saloon carriage constructed by the South Western Railway Company, and was briefly described in the *Engineer* of the 30th of November last. Brief reference to the steadiness and ease with which the carriage passes round sharp

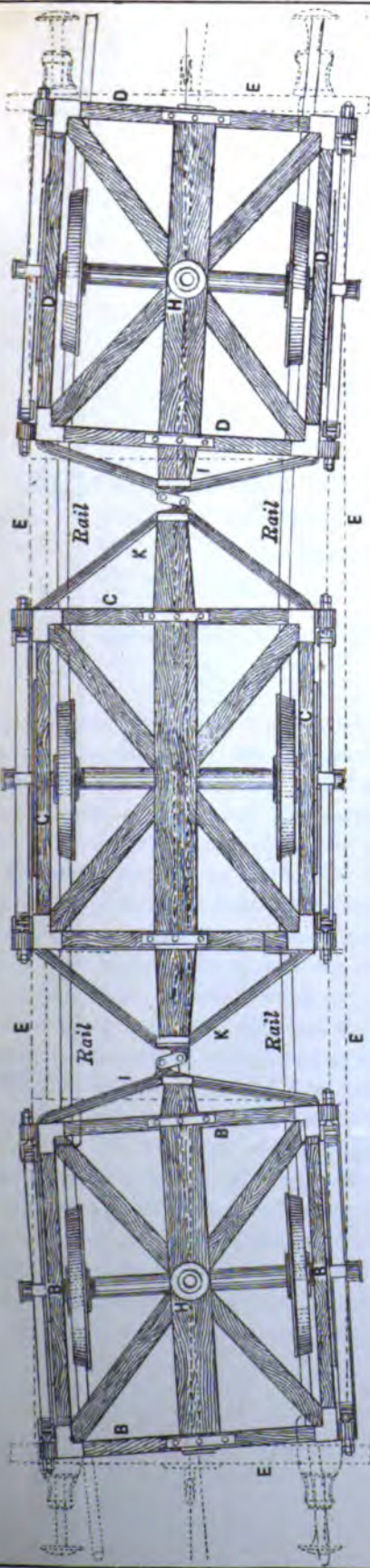
* Not reproduced.

curves was made on page 75 of the current volume. Carriages on the system described have been running for about a year on the London, Chatham, and Dover Railway, and any passenger travelling from Chatham to London will be able to make the journey in the old and new carriages, and prove for himself the great difference in the comfort of the two systems, especially when travelling by the boat express from Chatham to Herne-hill. The line is notoriously crooked, but it is on such lines that the new carriages show their great superiority in steadiness and smoothness in running.

"Besides being in use on the lines referred to, a number of pairs of short Metropolitan carriages are being converted into single long carriages on the new system by splicing, and a large quantity of stock is running on the Campanhia Paulista Railway of South America. Several English companies are making up whole trains, and a somewhat remarkable example of the application of the system is its use on the North Wales Narrow Gauge Railway. The gauge is 1 foot 11½ inches, and an official trial of a whole new train was recently made at a speed of twenty miles per hour, which, on a line which may be almost considered as a continuous set of curves of two chains radius, would be attended with the greatest danger with any other stock. The stock has hitherto been of the bogie class, the carriages being 25 feet in length, carrying 30 passengers, and weighing 5½ tons. The new carriages are 30 feet long, carry 42 passengers, and weigh 4¼ tons each. The latter have thus 33 per cent. more accommodation and weigh 20 per cent. less than the former. The bogie carriages rock very much in passing round the two chain curves, but this is not the case with the new carriages, which have a wheel base of 23 feet, or more than one-sixth the radius of the sharpest curve. The economy in weight in this instance is, it will be seen, very great, and is illustrative, for though on the stock of full size railways the gain is not so much, it is very large in all cases. In proof of the merits of the system, we may point out that it is being regarded with much favour by many locomotive and carriage superintendents, who are necessarily not the least easily satisfied. The facts that the carriage is so thoroughly supported throughout its breadth and length, and that the existing frames, springs, hornplates, &c., are all applicable, as well as the general simplicity of the arrangement, very strongly recommend it."

JAMES CLEMINSON'S "FLEXIBLE WHEELBASE," OR RADIATING AXLES.

FIG. 2.



PLAN OF AXLE FRAMES ON A CURVE OF 100 FEET RADIUS

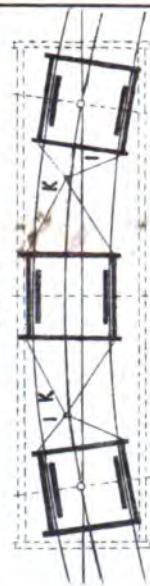
FIG. 6.



FIG. 4.



FIG. 5.



1

2

No. CCCXXX.

CLIP CALLIPER FOR LIFTING WASTE WEIR
PLANKING.

[*Vide Plate.*]

By A. HAYES, Esq., *Assistant Engineer, Cossye Division.*

THE accompanying drawing represents a clip calliper for lifting waste weir planking, designed by Mr. E. Raynean, Sub-Overseer, Cossye Division, formerly Dehree Training School Apprentice. During irrigation season, when it is necessary for the regulation of the supply to the various reaches to the pretty constantly raising and lowering the planks on the canal calingulahs, it has hitherto been necessary to send a khal-lasy down into the water to attach the loops of the lifting ropes to the wooden pins, driven for this purpose through each end of the planks, and this has been always rather a hazardous proceeding.

The present arrangement obviates any such necessity, for two khal-lasies standing on the one bridge each with a calliper, can grip the planks and raise or lower them as may be desirable.

The following description of their action, in addition to the plan, will clearly explain the method of working the calliper.

Raising.—The two jaws of the calliper weighted at the upper extremities with two cylindrical weights when opened out for the purpose of gripping a plank, are retained in position by a bent hook catch A. The calliper is provided with two sockets BB, in order to allow of its being attached to, and sliding on, a guide rod. When used in still water the guide rod is not required, and the calliper can be lowered fairly on to the plank, attached to a rope, but in an overfall of 2 to 4 feet or

more, the use of the guide rod is indispensable. The guide rod is provided at its lower end with an elbow iron point, which, as the rod is carried down by the stream, catches on the face of the planking, and allows of the rod being brought to a vertical position in the current.

The rod being dropped well ahead of the planking and brought vertical (*Fig. 1*), the calliper with jaws open and set, and the upper catch inverted, is lowered by a line down the rod until the convex portion of the bent hook A, coming in contact with the planking the catch is freed, and the jaws close in an immovable grip, the calliper assuming the position of the dotted lines. Both rod and calliper can now be hauled up with the plank or the rod detached, and the calliper and plank raised.

Lowering.—When it is desired to lower a plank, the plank is gripped as per *Fig. 2*, and the calliper lowered, the upper catch C being slipped up above its notch. On the plank reaching its place, the lowering rope is slackened, and the upper extremities of the jaws opening the upper catch C falls down into its notch, retaining the jaws open and the plank is freed, the calliper assuming the position of the dotted lines. It is generally found in a current that an additional blow or two with a rammer from above is necessary to overcome the friction of the plank against the grooves and drive it fairly down.

The main dimension and weight of a calliper is as follows :—

	Weight.					
Jaws, flat iron (over all) 1' 6" × 1½" × ½"						
Sockets, pins and other parts,	...	...	...	...	...	8 lbs.
2 Lead weights,	...	...	...	...	...	7 "
Total weight of calliper, 15 "						

Rod 15' × 1½" × 1½".

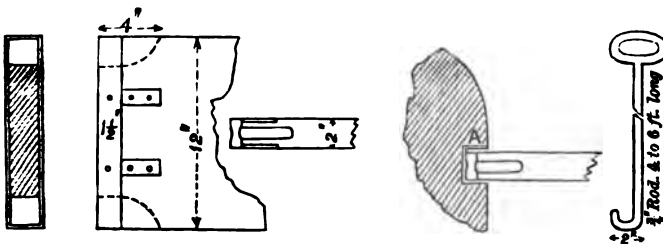
The dimensions of the calingulah planks are 5' × 1' × 2½". The head lock stop planks to prevent silt getting into the lock in flood time, dimensions 20' × 6" × 4" are also lifted with a pair of callipers. The planking should be slightly notched to enable calliper jaws to obtain a securer hold.

A. H.

EDITOR'S NOTE.—Practice with a simpler tool, see *Fig. A*, produces a fair result. The Dadupur dam, West Jamna Canal, over the branch of the Jamna, has 60 openings of 10 feet breadth, 4 to 6½ feet deep, closed

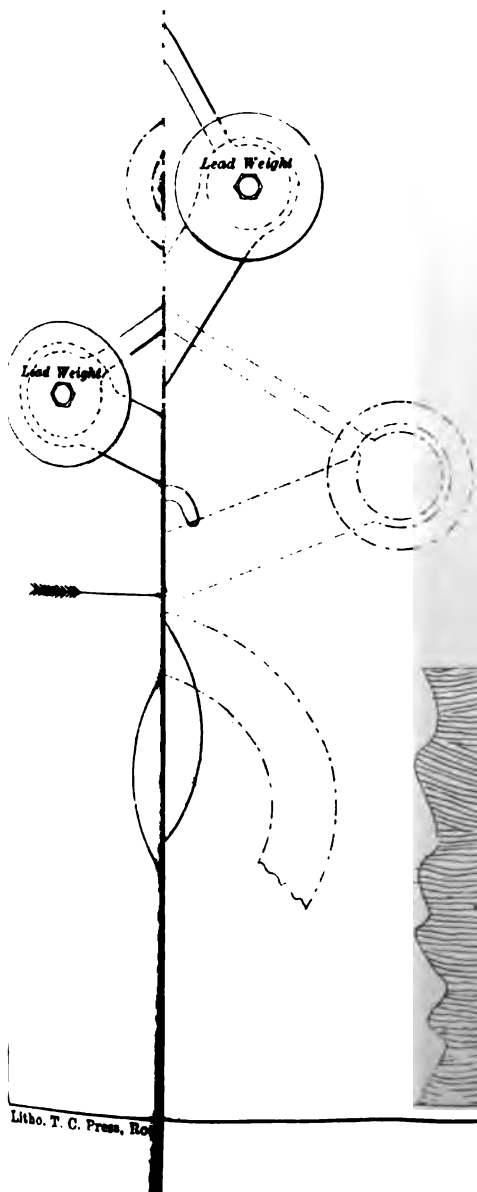
by about 290 planks. On approach of flood, about 230 of these are taken out and carried to banks by 45 men in two hours. The carrying is of course the heavy work requiring the number. Only 8 men are employed in lifting planks. The lower planks are of course lifted under 4 to 6 feet head and rush of water. Two hours is the night time, one and a half is sufficient in day light. This is rather smart practice, and I enter

Detail of end of plank at A.

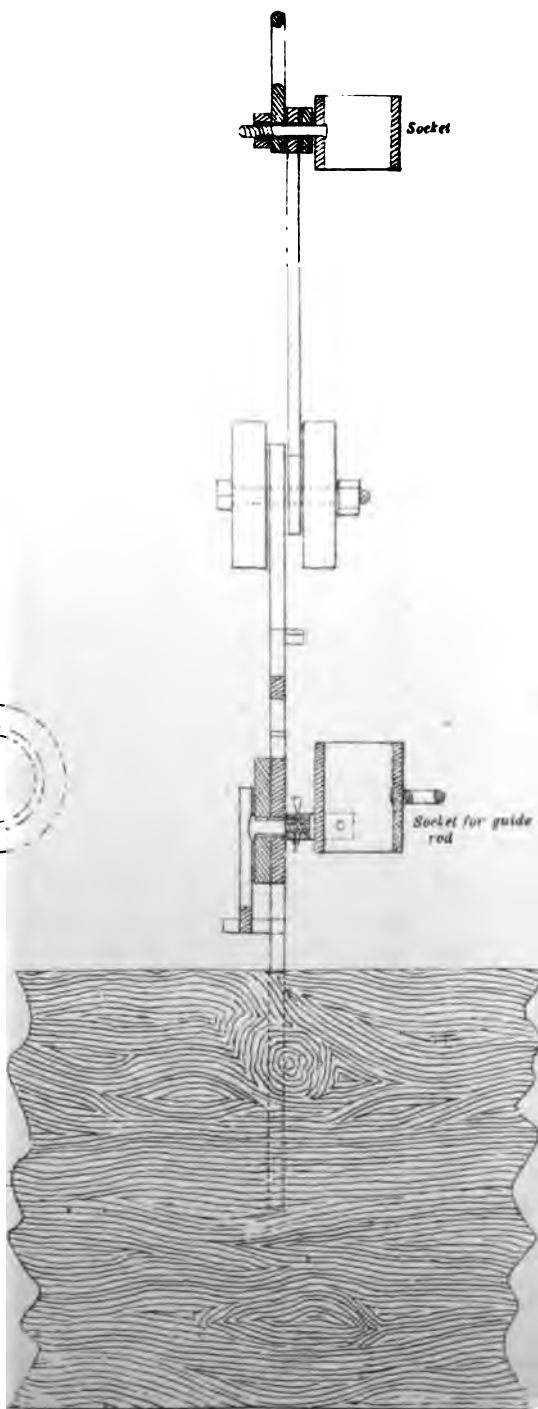


it here more as a bit of information as to what can be done, than to detract from the invention alongside. This is useful in cases of very deep water where a rod would be long and unwieldy, but the fact that the catch on the plank is in the groove in the pier makes it easy to find.

FIG. 1
POSITION
 The dotted lines thus —
 position of the Callipers
 being released by the set
 on plant the claws take the



SECTION THROUGH A B.



No. CCCXXXI.

ELECTRICAL INTER-COMMUNICATION IN TRAINS.

[*Vide Plate*].

By G. K. WINTER, Esq., F.R.A.S., M.S.T.E., *Telegraph Engineer,
Madras Railway.*

AMONGST the numerous applications of Electricity, the rapid communication of intelligence from one place to another is that which has received the greatest development, and it is certainly the use to which this wonderful agent appears to be most specially adapted. In the early days of its employment for this purpose it was thought uncertain and capricious, but as time went on, difficulties one after another disappeared; its action, before uncertain, became more and more under control, and its very caprices have been found subject to law, and have been converted into some of the most useful of its attributes.

Inter-communication in trains, or the communication of intelligence from one part of a train to another, has received a large amount of attention, and much ingenuity has been devoted to the solution of the problem. The fact, however, that no system has been universally adopted would tend to show that no system hitherto brought forward is practically perfect. Captain Tyler has said that electricity offers the best promise of success, and in this view most men acquainted with the present state of electrical science would probably concur.

In looking carefully into the question of the merits and demerits of the various existing electrical methods, with a view of discovering the best system for adoption on the Madras Railway, I found that the use of the wheels and rails as an "earth" or return circuit, and the use of special electrical couplings, were nearly universal. A few experiments were sufficient to convince me that in India, at least, we could not make

this use of the wheels and rails, for even supposing the electrical contact between the framework and the axles to be perfect, that between rail and rail could not be relied on, especially in dry weather; and with regard to the special electrical coupling, a little consideration was sufficient to show that any system which involved any extra labor or attention in forming or shunting trains, was unsuitable to our mixed and ever-changing traffic. There seems also to be little doubt that any difficulties which have been found to attend the application of the electrical systems hitherto proposed have been due to negligence or forgetfulness in forming the extra coupling, or to the imperfect earth formed by the wheels and rails; a coating of snow for instance over the rail would destroy communication even in England. The motion and consequent vibration of a train, on the contrary, presents no difficulty which cannot be easily overcome.

My endeavours have therefore been directed to the adaptation of the existing couplings to the purposes of communication, and to doing away with the necessity of using the wheels and rails as an earth. The result is a system which has been well tried on the Madras Railway, and has, I believe, given satisfaction to all who have seen it. It is impossible for any mistake to be made by the porters in forming or shunting a train, for they have only to do the work they have been always accustomed to, and it is impossible for any quantity of dust, tar, dirt, or grease on the surfaces of the hooks to damage in the slightest degree the integrity of the circuit, for the hooks are self-cleansing, and the weight of the chains is sufficient to insure the perfection of the contact.

Having abandoned the use of the wheels and rails as an earth, we require two conductors, insulated from each other, running from one end of the train to the other. This is simple enough as far as the carriages themselves are concerned, but the most difficult as well as the most important point is the mode of connecting electrically the conductors of one carriage, with the corresponding conductors of the next. This connection I accomplish by means of the side or safety chains in the following way :—

A strong and flexible cable is passed through the links of the chain; the conductors of this cable form a continuation of one of the insulated conductors of the carriage, and are fastened electrically to the hook at the end of the chain.

The cables are made by winding galvanized iron binding wire, weighing about 100 lbs. to the mile, helically round $1\frac{1}{2}$ inch tarred hemp rope, in the grooves between the strands. The end of this cable, which is to be attached to the hook at the end of the chain, is close bound with the same binding wire for a length of about 3 inches, and the ends of the wires projecting beyond the hemp rope are twisted together into a wire rope.

Two holes are drilled through the shank of the hook about $1\frac{1}{2}$ inches apart, and into these holes tinned iron eye bolts are soldered. The ring of the eye bolt nearest the end of hook is only large enough to admit the wire rope projecting beyond the cable, while the other is large enough to admit the cable together with the extra binding. The bound end of the cable is passed through the large eye bolt and carried as far as the small one, through which the wire rope is passed, and to which it is firmly soldered; the rope is then unwound and spread radially over the ring of the bolt, and again firmly soldered on to its surface, the ends of the wire being cut off if too long. The lower end of the cable being thus firmly fastened to the shank of the hook, the cable is passed through the links of the chain in the most convenient manner, and finally passed through a hole in the buffer plank of the carriage, the wires of the cable are then soldered to the end of one of the wires running underneath the vehicle. The chain and cable are well coated with tar, except on the inner surface of the hook.

The next point to be considered is the best mode of securing good electrical contact between the hook of one chain and that of the next carriage, when they are coupled. On the electrical condition of this contact depends the success or failure of the system, I have therefore spared no pains to ensure its perfection. The shape of the hook is first altered from the ordinary form shown in *Fig. 1* to that shown in *Fig. 2*. To secure uniformity and correctness of figure, a steel or iron die is made of the shape shown in *Fig. 3*. The hooks are made red-hot, and are easily altered into the required shape by first driving the die between the jaws of the hook, and then completing the alteration by means of the hammer, keeping the die in its place during the operation. The bearing surface of the hook is then coated with a piece of sheet copper which is brazed on, and finally a small rib of gun-metal of semicircular section is soldered on to the inside of the outer jaw of the hook. *Fig. 4* is a drawing of

a complete chain with cable, &c., and *Fig. 5* is an enlarged drawing of the hook with its copper lining, and gun-metal rib.

It has been found that with hooks prepared as above, neither grease, tar, nor dust, are able to impare the contact of hook with hook, and the small stones, which are occasionally thrown upon the chains from the ballast, are unable to insinuate themselves between the acting surfaces.

The method of working adopted on the Madras Railway is very simple, and might be still further simplified could a battery be conveniently placed on the engine.

A battery is placed in each brake van, and all batteries are so connected that they always tend to send a current in the same direction. The circuit is always open except when closed by pressing a plunger in the act of signalling. The disposition of the apparatus in a train will be understood from *Fig. 6*.

All that is necessary is to have a brake van between the passenger carriages and the engine, and even this rule would be rendered unnecessary, if we could place the battery on the engine, instead of in the vans. This system has been working exceedingly well on the Madras Railway, since the 1st January 1879, the daily train mileage worked being about 1,776 miles. The fitting of the whole stock of the Railway is being rapidly proceeded with, and at an early date the whole of the trains running on the Railway will be provided with an efficient means of communication between the Guards and Passengers and the Driver. The arrangements are tested on leaving or passing through each station, by the Guard in the rear van giving an all right signal to the Driver, and any failure or irregularity in the working of the apparatus is entered in the Guard's and Driver's Journals, and is reported to the Heads of their respective Departments, so that the letters that have been given me by the Traffic Manager and Locomotive Superintendent are written with full knowledge of the manner in which the system has worked.

It has not been thought necessary hitherto to apply a break-away signal to the system on the Madras Railway, and the author does not recommend its adoption, owing to the complication necessarily involved: it can however be applied in several ways, of which the following arrangement is probably the cheapest, simplest, and most easily applied.

The closed circuit is used, and signals are made by breaking or opening the circuit, so that if a train parts a signal is given automatically in consequence of the break in the circuit, caused by the parting of the train. The difficulty which has hitherto prevented this system from being adopted is that during shunting, or when the engine is separated from the train, the engine bell would be continually ringing, unless some act were performed to stop the ringing; and, in this case, there is always the danger of the apparatus not being re-adjusted for ringing, when the train is made up again. This difficulty I propose to overcome in the following simple manner.

A relay is used on the engine to complete the circuit of a local battery through the bell. This relay has two contacts, the armature making contact with the one when the train circuit is complete (that is when the constant current is flowing through the coils of the relay), and with the other when the train circuit is broken (that is when no current is flowing through the relay coils). A switch attached to the apparatus is arranged to join one contact with the battery and bell, when the switch handle is in one position, and the other contact with the battery and bell, when the handle is in its other position. Thus, suppose when the train is joined up, and the train circuit closed, the bell is silent when the switch handle is at A, and that it rings when the handle is at B; then, when the train is divided, and the train circuit broken, the bell will be silent when the handle is at B, and it will ring when the handle is at A. Thus on arriving at a station at which shunting is to be performed, directly the train is divided the bell will ring, and will continue to ring until the Driver turns the handle to B. Again, when the shunting is completed, and the train joined up again, the bell will ring until the Driver turns the handle back to A. So that, whether the train is being formed or broken, the Driver is reminded of the change to be made in the position of his switch handle, by the ringing of the bell, and there is consequently no chance of the proper adjustment being forgotten. The arrangement is shown in *Fig. 7*.

It will be seen that signals may be given to the Driver by simply dividing the circuit in any part of the train, and keys arranged to do this may be fixed in any or all of the vehicles. Also should any part of the train become separated, the act of separation will break the train circuit, and cause the bell to ring.

No. C $\frac{780\frac{1}{2}}{A. \& M.}$

From—H. E. CHURCH, Esq., *Traffic Manager, Madras Railway Company.*

To—G. K. WINTER, Esq., *Arconum.*

Madras, 9th October, 1879.

In reply to your enquiry as to our experience of the practical working of your electrical communication in trains, I have much pleasure in informing you that since its introduction, on the 1st January last, in the mail trains, it has worked most satisfactorily, and the comparatively few interruptions we have experienced have been found on enquiry to be due to carelessness on the part of the Train or Station staff, and not to any defect in the system.

The communication has been made use of by the public on more than one occasion, when a spark from the engine had set fire to clothes, or bedding, and there can be no doubt that it is much appreciated by the Train staff.

* * * * *

No. $\frac{3224}{4626}$

From—F. H. TREVITHICK, Esq., *Locomotive Superintendent, Madras Railway.*

To—G. K. WINTER, Esq., *Telegraph Engineer, Arconum.*

Perambore Works, 27th November, 1879.

In compliance with your request that I should express an opinion upon the working of your electric inter-communication apparatus, I have much pleasure in testifying to the success with which it has been worked during the last 11 months on this Railway.

The apparatus is now fitted to nearly all the engines on this line; it has done good service to passengers on the occasions when it has been needed by them, and as far as I know, has not once failed from any defect in the apparatus.

The bell on the engine always rings, and so clear and strong in answer to the Guard's touch on the key in his van, that it has often occurred to me that the use of the apparatus ought to be extended by the adoption of some simple Code, so as to enable the Guards to communicate much more than an order to stop, or a signal that all is right

behind. It would be most useful as a starting signal, especially for long goods trains on dark and stormy nights.

As there is no machinery to get out of order; as it requires no special couplings between the vehicles, and admits of easy application to foreign stock mixed up in the trains, and as, above all, it has now stood quite successfully the practical test of a year's working, I have no hesitation in asserting it to be the best inter-communication scheme yet brought out.

Extract from a letter from the Agent and Manager, to the Secretary, Madras Railway Company, No. 1888, dated the 18th of October, 1879.

From the 1st of January last the mail trains have been provided with electrical inter-communication between Guards and Passengers and the Drivers, and since the 1st of February the 7 A.M. and 6-15 A.M. passenger trains have also been similarly provided, the working of which in all cases has been satisfactory.

G. K. W.

ELECTRICAL INTER-COMMUNICATION IN TRAINS.

FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.

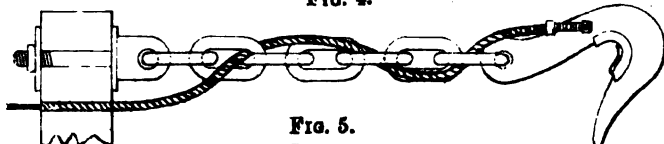


FIG. 5.

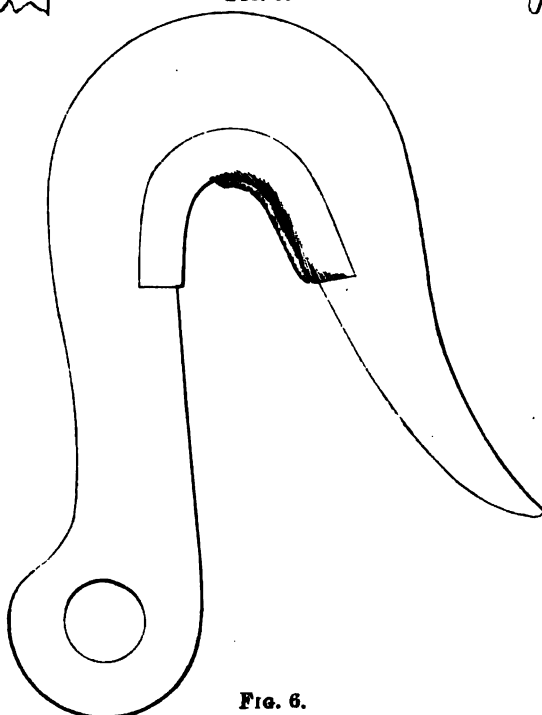


FIG. 6.

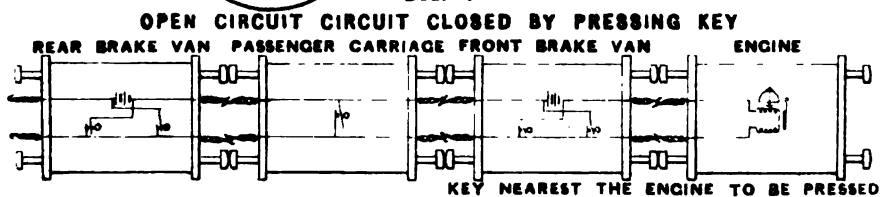
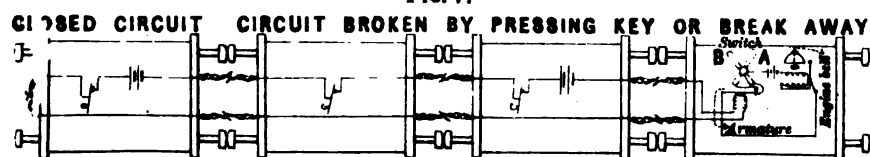


FIG. 7.



ELECTRICAL INTER-COMMUNICATION IN TRAINS.

FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.

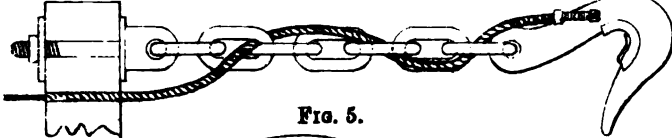


FIG. 5.

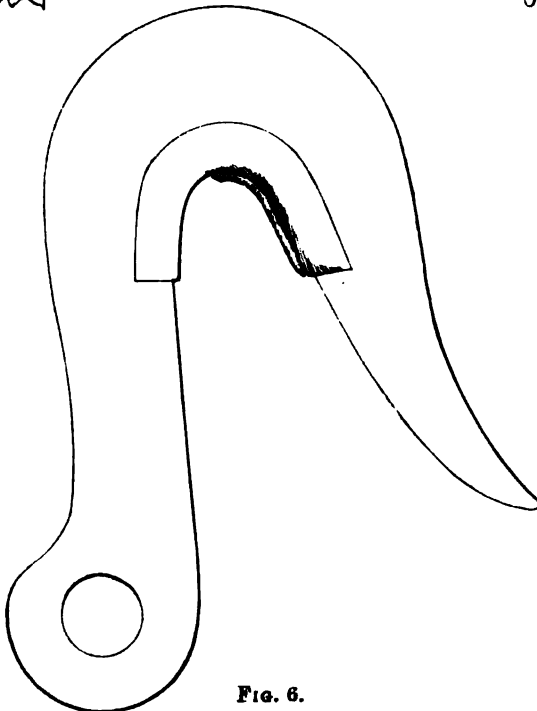


FIG. 6.

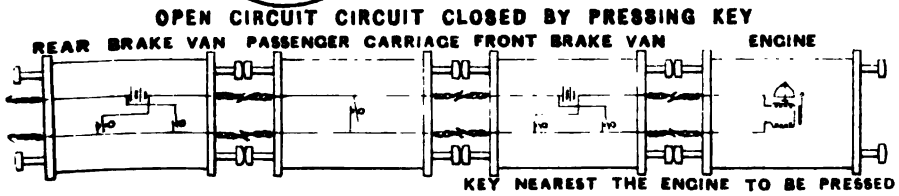
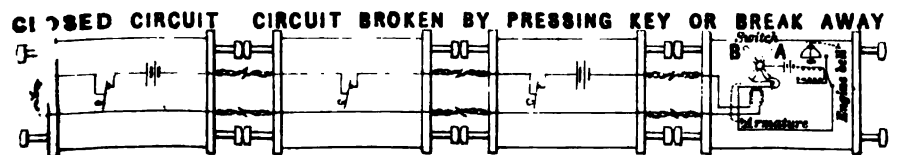
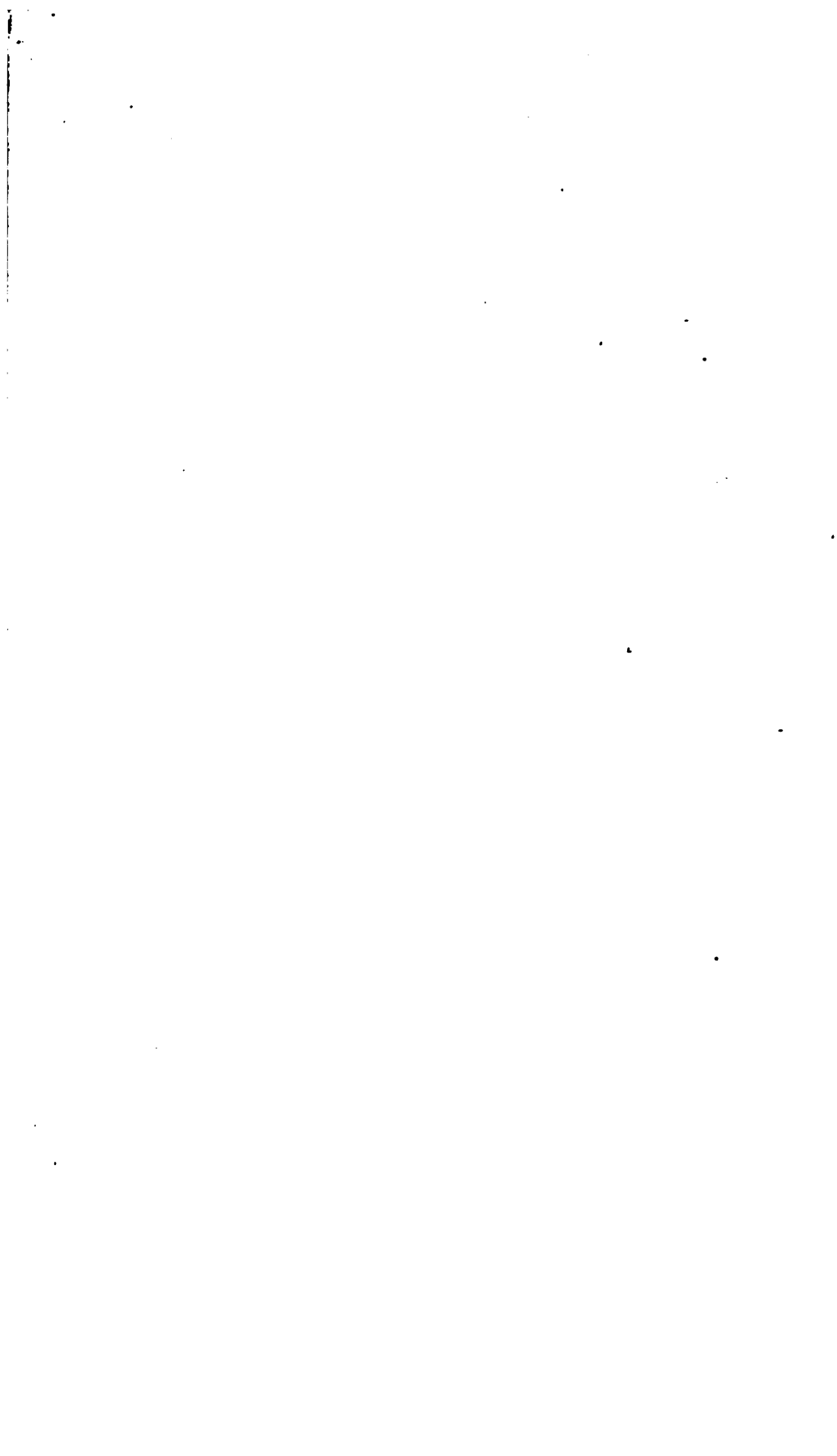


FIG. 7.





No. CCCXXXII.

ALFRED NOBEL'S DYNAMITE.

[*Vide* Plates I., II., and III.]

BY MAJOR J. L. L. MORANT, R.E., *Executive Engineer.*

THE supremacy of gunpowder as the only safe and economical blasting agent has for some time been a thing of the past. The advantage offered by explosives more violent in character has become widely known and utilized. Of all these explosives, those in which nitro-glycerine is the chief constituent have received the widest application. And of these latter, dynamite is the one which seems best adapted for India. It is now, and has for some years been, very largely employed all over Europe; and in some places has, for blasting purposes, entirely superseded powder, notwithstanding the greater care now bestowed upon the manufacture, and the improvements introduced into the nature and form, of powder.

Its increasing consumption.—In Europe, America and Australia its annual consumption is now considerably over 5,000 tons: and this consumption has been increasing since its introduction as follows:—

Year.						Tons.
In 1867, ...	...	...	...	...	...	11
" 1868, ...	...	...	...	...	...	78
" 1869, ...	...	...	...	...	...	185
" 1870, ...	...	...	...	...	...	424
" 1871, ...	...	...	...	...	...	785
" 1872, ...	...	...	...	...	...	1,350
" 1873, ...	...	...	...	...	...	2,050
" 1874, ...	...	...	...	...	...	3,120
" 1875, ...	...	...	...	...	...	4,000
" 1876, ...	...	...	...	...	...	5,000

I have not been able to obtain the figures since 1876.

Gelatine Dynamite.—Nor has the *ultima Thule* in dynamite been yet reached : M. Nobel is now introducing a gelatine dynamite which has already, to an important extent, supplanted the Kieselgurh dynamite on the Continent of Europe. He has now discovered that a comparatively small quantity of a nitrated cellulose, prepared from cotton in a peculiar manner, has the property of transforming liquid nitro-glycerine into a gelatinous mass highly suitable as an explosive, possessing twice the destructive force of dynamite No. 1, at only 60 per cent. greater cost in the explosive. Gelatine dynamite is composed of—

Nitro-glycerine,	...	...	...	...	86.40 parts.
Soluble gun-cotton,	...	...	...	...	9.60 "
Camphor,	...	...	...	...	4.00 "
					<hr/>
					100.00 "
					<hr/>

It possesses the following extraordinary qualities :—

(i), It may be preserved intact for an indefinite time under water, so that it is even proposed to store it by keeping it immersed in water till required for use ; (ii), it never gives off its nitro-glycerine even under extreme pressure ; (iii), it is unaffected by violent shocks or vibrations and even by explosions which may occur close beside it, and (iv), it is not affected dangerously by fire.

Nobel's Dynamite, No. 1.—The blasting gelatine is not, however, in some respects, so suitable for Indian Engineering as the Kieselgurh dynamite, or Nobel's Dynamite No. 1, as it is called by the Trade. The following remarks will refer almost solely to the Kieselgurh mixture. They will be followed in a succeeding number by a record of certain special experiments carried out in India on the effective use of dynamite in rock blasting.

Advantages of Dynamite.—Dynamite offers the following advantages :—

1. Its explosive effect is much more violent than that of powder, and it requires fewer bore holes than powder does, hence saving in labour, tools, explosive, and fuze.

2. Not only is a much larger quantity of powder than of dynamite required to produce similar results ; but it is often impossible to perform the same operations even with exorbitantly large charges of powder : this is especially the case in the breaking up of masses of hard rock or metal by the super-position or simple insertion into cavities of the dynamite.

It is hence invaluable on field service, or wherever work has to be instantaneously done (as in the case of a mountain road suddenly blocked against traffic by a storm), or wherever time is of greater importance than a larger expenditure of the explosive.

3. In hard rock the shattering and splitting effect of dynamite is much greater than with powder; and the rock is broken up to the bottom and sometimes beyond: it hence cheapens the after removal of the shattered rock, and is peculiarly advantageous in obtaining broken stone for roads.

4. Its density being nearly double that of powder, and its power very much greater, its bore holes can be made smaller than those for powder.

5. To a certain extent, and for limited periods, dynamite is unaffected by dampness: there is therefore no necessity to dry the holes as when powder is used, and it is also without difficulty usable in water bleeding rocks.

6. The explosion of dynamite being instantaneous, almost any kind of tamping suffices; or, at least, tamping is not nearly so important in employing dynamite as it is in using powder. Water is often used as tamping; and in case of a miss fire this is extremely convenient, for the primer and fuze have simply to be withdrawn and another primer and fuze inserted.

7. Dynamite cannot be exploded by simple ignition: it must be exploded by violent detonation. Hence its great safety as an explosive. Even if its store be on fire, it will burn for a considerable time before it can explode. And though it can be exploded by a shock, this shock must be of such a character as it is very unlikely to meet with in practice. There is hence less danger in the transport of dynamite than in that of powder.

8. Dynamite possesses the advantage over gunpowder of producing, when fully and properly exploded, but little smoke; but if a hole be overcharged, or if the explosion be imperfect, then the vapours evolved from dynamite are more objectionable than gunpowder smoke.

9. The manufacture of dynamite is conducted with greater safety than that of gunpowder: though several thousands of tons of the former have been made in England not a single life has been lost among the numerous workers employed.

10. The few precautions required in using dynamite are perfectly simple, easily understood, and easily carried out.

11. English dynamite is not liable to explode spontaneously: no instance has ever occurred of its so doing. The following Table will make readers assured of this:—

The undermentioned articles give off an inflammable gas which forms an explosive mixture with the air at the following temperatures:—

							Fahrenheit.
Ether,	...	...	...	...	...	...	88°
Parrafin oil,	...	...	...	...	...	...	120° to 150°
Naptha,	...	...	...	...	...	...	150°
Alcohol, Brandy, Whiskey, &c.,	...	...	...	...	...	...	170°
Benzol,	...	...	...	...	...	...	176°
Turpentine,	...	...	...	...	...	...	320°

Whilst the undermentioned articles explode spontaneously at the following heats:—

							Fahrenheit.
Dynamite,	...	...	...	...	...	...	400° to 420°
Gunpowder,	...	...	...	...	...	...	500° to 600°

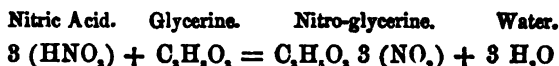
12. In store the risk of an explosion of dynamite is almost nil.

Its only drawback.—There is one drawback in the use of dynamite, and that is that it freezes at a temperature 14° (Fahr.) warmer than the freezing point of water, and when frozen it thaws very slowly, and can only be exploded with difficulty. This, its only weakness, is one that will not have to be tested in most parts of India.

Sun's action on Dynamite.—A more important point in this country is the action upon it of sun-light and heat. Professor James Dewar experimented in midsummer upon dynamite in the following way:—Having placed some dynamite in an exhausted tube, it was heated for several hours on successive days by a current of steam, the tube being at the same time freely exposed to the action of light. This treatment gave no trace of any permanent gas or acid, and the substance showed no trace of any decomposition. At the same time it is very advisable that dynamite be never long exposed to the direct rays of the sun. At 158° Fahr. several grammes of nitro-glycerine will disappear from dynamite in a few days if exposed in thin layers in watch glasses. But from experiments on the Continent of Europe, in 5 years a sample of 1871 lost only 2·2 per cent., and in 4 years a sample of 1872 lost only

1.5 per cent. of its nitro-glycerine. Dynamite freely exposed to the air, however, must in course of years lose an important percentage of its active principle.

Dynamite how discovered.—Nitro-glycerine, discovered by a young Italian Chemist, Sobrero, at Paris in 1847, is formed by the action of nitric acid on glycerine—



Concentrated sulphuric acid is added to remove the water formed, the heat evolved being artificially kept down to prevent the decomposition of the nitro-glycerine. Being only capable of partial explosion by ordinary methods, nitro-glycerine continued useless till the Swedish Engineer, Alfred Nobel, discovered the method of its complete and certain explosion by a detonator of fulminate of mercury. But the catastrophes resulting from its accidental explosion led to its abandonment. Nobel, however, in 1864 discovered that by mixing with the nitro-glycerine a porous infusorial siliceous earth, known in Germany as Kieselgurh (or any other absorbent substance), it not only retained its blasting powers, but that the readiness and certainty with which the nitro-glycerine exploded was somewhat favored by the mixture. Hence the introduction to the public of dynamite in 1867.

Two classes of Dynamite.—Dynamite is made of various strengths in two classes: one class in which the absorbent material is inert, serving only as a carrier for the oil; the other class which contains an active base—itsself an explosive. Of these two classes the first is by far the most powerful, the second is little better than gunpowder. In the first class it is not only necessary that the mixture be complete, but that the oil be entirely absorbed, so that no separation can after mixture be possible either from movement in transport or from long storage. The complete admixture of its two ingredients is of great importance, and is effected by means of sieves and heating to 160° Fahr.

Characteristics of Dynamite.—All reliable dynamites possess the following characteristics:—

In appearance they are greasy and plastic like putty; when uncooled, flesh colored, and when frozen, white; their density is 1.6, that of powder being 1.00; they burn quietly when exposed to a flame without producing any explosion, but when heated to 420° Fahr. they explode;

they can only be practically exploded by a cap or detonator, and when confined, the force of the explosion varies with the strength of the envelope; they are unaffected by exposure to damp, and in some kinds even by immersion in water; they freeze at a temperature 14° (Fahr.) warmer than the freezing point of water, and in this state are less readily exploded; their perfect explosion generates no noxious gases, though their burning does, but though the fumes are poisonous, habitual contact diminishes their hurtful effects; and, lastly, moderate shocks do not affect dynamite at all.

Dynamite Cartridges.—English dynamite has been manufactured under strict Government supervision since 1873 at Ardeer near Stevenston in Ayrshire by Nobels Explosives Company; Indian Agents, Messrs. Macaulay and Company, Bombay; Indian Instructor, Mr. John Harris. Nobel's Dynamite No. 1 is sold in cylindrical cartridges with a wrapper of parchment, which is thick, untearable, and impermeable to nitro-glycerine, though not to water, so that should the oil separate it cannot pass to the outside. These cartridges are consolidated by pressure, whereby any excess of nitro-glycerine, which the porous earth will not hold absorbed, is expelled. Each cartridge is $\frac{7}{8}$ -inch in diameter, $3\frac{1}{2}$ inches long, and weighs 2 ounces: eight cartridges therefore go to the lb. The cartridges are made up in 5 lb. packages (with 37 cartridges and 9 primers, latter weighing each $\frac{3}{8}$ oz.) covered by a wrapper of oil skin which is waterproof, but not nitro-glycerine proof. Ten of these packages are packed in each wooden case, containing therefore 50 lbs. of dynamite. A ton of dynamite, like gunpowder, weighs 2,000 lbs.

Prices of Dynamite.—The prices of Nobel's Dynamite No. 1 with its appurtenances at any Indian Sea Port are as follows:—

				PRICES.		
				Rs.	As.	P.
Dynamite No. 1, per lb.,	...	...	...	1	8	0
Treble Detonators, per box of 100,	...	...	...	2	2	0
Nippers for fastening detonators to fuze, each,	...	...	...	0	6	0
Improved nippers for ditto, each,	...	...	...	2	0	0
Gutta-percha (tape) safety fuze, (Bickford's) for blasting in						
wet places and for submarine work, per coil of 24 feet,	...	...	...	1	2	0
Red tape safety fuze, per coil of 24 feet,...	...	...	...	0	7	0
White tape fuze, " "	...	...	...	0	8	0
Electric fuzes $4\frac{1}{2}$ feet long, each,	...	...	...	2	0	0

Large India-rubber lined bags for extra heavy blasts are supplied to order.

Detonating Caps.—In practice, dynamite is exploded by means of heavily charged percussion caps, of which *Fig. 1* is a full size section.

The amount of charge in a detonating cap affords no indication of its strength, since it may vary in chemical composition. Some caps with a charge of 15 grains failed to explode a frozen primer, while other caps containing only $4\frac{1}{2}$ grains succeeded.

This is caused by (i), impurity of the fulminate of mercury; (ii), the chlorate of potash with which it is mixed may be in excess; or (iii), the quantity of gum used to bind the charge and to protect it from moisture may be too great. The proper proportions in the fulminate giving the best results are:—

Fulminate of Mercury,	...	...	...	...	77.66 per cent.
Chlorate of Potash, ...	...	...	...	...	22.34 „
					100.00

To ensure the detonation of dynamite under all conditions, the detonator used must be capable of rupturing an iron plate .03 inch thick when tied to it by a string. To illustrate the force of these detonators, it may be mentioned that a school boy at Halifax lost the fingers and thumb of his left hand by a detonator exploding in it. Two years previously a man had bought some detonators for exploding dynamite, but having no use for some of them, he soaked them in water to render them as he thought harmless, and threw them into the street, where one was picked up by the school boy, who seeing a white substance at the end of the tube, tried to extract it with a pin, when the detonator exploded.

Fuze fastened to detonator.—These detonating caps are laid in small tin boxes in sawdust; before using the caps, the sawdust must be blown out with a dry blow of the mouth: they must never be scraped. Bickford's fuze is used, cut to the requisite lengths with square ends, one of which is inserted in the cap until it touches the fulminate: the cap is then compressed with pincers near the open end, so as to bind and hold the fuze tightly.

Fig. 2 shows the detail, W being the compressed portion. *Fig. 2A* also further illustrates this.

Pliers used by wire workers are the most convenient, the cutting edges being first blunted: care must be taken that the pressure used is not too great, lest the fuze be separated from the fulminate, and the circulation of the flame be impeded. In wet or even damp places the junction is

made water-tight with grease, white lead or tar smeared well over the whole portion of cap and fuze near W, *Fig. 2*.

Primers.—The fuze and cap being ready, a primer (weighing $\frac{3}{4}$ oz.) is opened at one end, and the cap is gently pushed into the dynamite, so that a part of it is still visible; or if desired, a slender piece of box wood, termed a "regulator," with a shoulder to fix the depth up to which the cap can be inserted, is first pressed into the dynamite to form the hole for the receipt of the detonating cap. Care must be taken not to push the cap overhead into the primer, or the fuze will set it on fire and burn and waste the dynamite; or the flame of the fuze may ignite the dynamite, and the cap explode out of contact, when there would be no explosion of the dynamite. The cap inserted, the paper of the primer is then closed up, and bound round the fuze with a wire or piece of twine as shown in *Figs. 3* and *3A*, B being the binder.

The connection ought to be very securely made, so as to prevent the displacement of the cap.

Loading and Firing.—In making a blast, one cartridge is first placed in the bore hole and *pressed or squeezed, not rammed*, down with a *wooden, never an iron or metal*, rod in such a way that it forms a close contact with the sides of the rock: this process is repeated with a second, third or more cartridges according to the magnitude of the blast. Finally the primer, furnished with the cap and fuze, is lowered or pushed gently, but never rammed, into the bore hole until it rests on the charge. However heavy the charge may be, it is always advisable to employ a small exploding cartridge or primer. The space for about 8 inches above the charge is then gently filled with sand, clay or soil, and the rest of the tamping is formed of any more resisting material that may be at hand, gently packed with the wooden rammer. [Damp sand lightly packed forms an excellent tamping. Or water may be simply poured into the hole]. After this is done the fuze may be lighted. See *Fig. 4*.

When a blast has failed, the charge should not be withdrawn, unless water tamping has been used: such an operation would be attended with great danger. A fresh charge should be placed in a hole made near the former, and the explosion of this will generally insure that of the other; or about half the tamping may be removed, and a heavily capped cartridge introduced.

Frozen Dynamite.—Dynamite becomes frozen at 46° Fahr., but thaws slowly and resumes its pasty condition when warmed. Thoroughly congealed dynamite appears no longer flesh colored but white. To secure its full explosive effect, dynamite must be in the pasty state when used. It should not, as a rule, be applied in any way for blasting in a hard or frozen state. It is not dangerous when frozen, in which state it can be carried rather more safely than when unfrozen: but when frozen it can only be exploded with difficulty, and, by not fitting into the bore hole, it loses some of its explosive effect: it also thaws so slowly as to make the bringing it to a plastic condition a tedious matter: most of the accidents which have occurred in its use have arisen from attempts to thaw it quickly. Where circumstances do not readily admit of the charge of dynamite being thawed, the primer cartridge must at least be first thawed by placing it in the trowsers pocket: the primer thus used will explode the frozen dynamite.

It has been proved on a large scale that dynamite can be carried about, shaken, or even broken with impunity *when in a frozen state*. The following experiments among others, were made before Dr. James Thomson and Mr. J. T. Bottomley, Professor of Engineering and Lecturer on Science respectively, in the University of Glasgow. Several cartridges of dynamite in a frozen state were thrown, one by one, with great force against an iron plate: the cartridges were partly squeezed into lumps sticking to the plate, and partly were smashed to fragments which flew round about; but there was no explosion. A block of iron 400 lbs. weight was allowed to fall from a height of 20 feet on a light wooden box containing 20 lbs. of dynamite in a frozen state: the box was smashed, the cartridges crushed flat and pounded together, but no explosion. The crushed frozen cartridges were next made up into two heaps to be exploded. A small unfrozen cartridge or "primer" of dynamite, with detonator and fuze, was inserted in each frozen mass, and fixed successively, the two heaps of frozen dynamite being only a few yards apart. The explosion of the first, though very violent, did not set the other off. The second, however, made a very violent explosion when ignited by the unfrozen primer and detonator.

The freezing point of nitro-glycerine varies between 39° and 53° 6' Fahr., owing to differences in manufacture. Samples from Nobel's factory at Zamky on the Continent, remained liquid under from 32° to 17° 6'

Fahr. Dr. Gladstone has noticed that nitro-glycerine when subjected to cold will become only thick or glutinous without freezing. Other experiments have shown that in nitro-glycerine exposed for several days to 50° and 32° Fahr. some crystals became detached and floated on the oil which did not congeal. Contact with silicious substances, such as silicious marl, hastens the freezing at temperatures below 53° Fahr. With dynamites composed of absorbent matters having a combustible tendency, the diminution in liability to explode was rather lessened when frozen. Soft silicious dynamite would not explode when fired at and struck with a bullet at 2,500 paces; at 2,000 combustion was produced. Frozen dynamite, however, would not explode even at 60 paces. The following are the results of trials by striking dynamite samples with a steel hammer:—

Unfrozen dynamite.				Dynamite between frozen and liquid.			
Fall	19·7 inches		explosiop.	Fall	19·7 inches		explosion.
"	15·7	" ..	"	"	15·7	" ..	"
"	11·8	" ..	"	"	11·8	" ..	"
"	7·9	" ..	"	"	7·9	" ..	"
"	5·9	" ..	"	"	5·9	" ..	"
"	3·9	" ..	no explosion.	"	3·9	" ..	no explosion.
"	3·9	" 2 blows	"	"	3·9	" 2 blows	explosion.
"	3·9	" 3 blows	"	"	2·0	" ..	no explosion.
				"	2·0	" 2 blows	explosion.
				"	1·6	" ..	no explosion.
				"	1·6	" 2 blows	"
				"	1·6	" 3 blows	"

The sensibility of frozen nitro-glycerine to mechanical shocks is shown by the above experiments to be less than that of non-frozen nitro-glycerine, but in the transition state this sensibility is still further increased.

Frozen Dynamite how thawed.—To bring the dynamite from a frozen to a plastic condition, the most convenient arrangement is a double box, the inner one containing the cartridges, and the space outside it being packed with fresh manure. In this manner dynamite can always be preserved in a proper condition. In smaller quantities the apparatus shown in section in *Fig. 5* is employed.

It consists of two concentric vessels, the inner one containing the cartridges, and the outer one hot, *not boiling*, water.

Blasting under water.—If the blast is made under water, it is absolutely necessary that water be prevented from touching the cap. A simple method has been already described. Another special arrangement is seen in *Figs. 6 and 7*. Here an outer envelope or zinc box is packed with grease and wax in the space *W* left above the top of the cartridge.

Velocity of Dynamite.—Groups of mines may be exploded simultaneously by joining them with dynamite trains about 1 inch thick, which are made of rubber or zinc tubes filled with the explosive. To insure success, it is necessary to place a heavily charged cap at the end of each train.

Mr. Abel has exploded a cartridge of dynamite weighing $2\frac{1}{2}$ ounces at one end of a wrought-iron tube 5 feet long and 1.22 inch internal diameter, by exploding a similar cartridge at the other end. The velocity of transmission along a continuous train of dynamite is about 20,000 feet per second; but it is reduced to 6,200 feet when the cylinders of dynamite are placed half an inch apart; and from various experiments it appears that the transmission of explosion from one charge of dynamite to a separate one varies with the distance between them, with the amount of the initial charge, and with the nature of the packing of the recipient charge.

Safety in transport and store.—Major Majendie, R.A., the Government Inspector of Nobel's English Factory, reports that: "Dynamite of the specified composition and quality is safer to transport than gunpowder packed in barrels." Some of the grounds for this assertion may be here given. Boxes filled with dynamite have been thrown from a great height with a great shock without exploding. They have been placed on an open fire when the dynamite burned slowly away without exploding. Dynamite has been in railway collisions, and, though the van and boxes containing it were smashed, no explosion took place. In Bombay, piece of iron weighing 250 lbs. was dropped 40 feet on a box of 50 lbs. of dynamite; box broken, dynamite scattered but not exploded. At Bombay one lb. of gunpowder scattered over 5 lbs. package of dynamite and exploded: no explosion of dynamite. Again, an iron plate was placed on 20 lbs. of powder, and on the plate 10 lbs. of dynamite: explosion of powder sent iron plate quarter of a mile into the air; fragments of parchment, with unexploded dynamite adhering, found lying

on the ground. There are 14 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 the present time that the danger of dynamite in 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.

Dynamite how used.—Absolute instructions for the use of dynamite cannot be laid down any more than for the use of powder: everything depends on the nature of the rocks and the character of the work. Exactly parallel experiments are extremely difficult to obtain. Comparative experiments with explosives on masses of *concrete* would seem to promise fairer results than when tried on rocks, the homogeneity, nature and condition of which vary even in the same species of rock, and are next to impossible to predicate.

The following general principles, however, may be observed. The mode of proceeding is the same as for powder, only the holes should be further apart, of less depth and of smaller diameter, so as to obtain a more slender charge.

Bore holes for Dynamite.—The following are the diameters of the drills usually employed for different depths:—

					Diameter.
From 8 feet to 6 feet, ...	...	...	...	1 inch.	
" 6 " 11 " ...	...	...	...	1½ to 2 inches.	
" 11 " 15½ " ...	...	...	...	2 to 2½ "	

The depth of the bore hole should be not less than equal to the length of the line of least resistance, and in no case should the bottom of the hole descend below the level of the face of the rock.

Calculations of charges.—When the rock is very compact, the length of the charge is made about $\frac{1}{2}$ the depth of the hole, in more favorable cases it may be $\frac{1}{3}$ or even $\frac{1}{4}$. The following formulæ may be employed in calculating the charges to be used.

$$W = \frac{C}{24} \cdot \overline{L.L.R.}^3 \text{ or } = \frac{C}{82} \cdot \overline{L.L.R.}^3 \dots\dots\dots (1).$$

Where W = the weight of the charge in lbs., Avoirdupois,

$L.L.R.$ = Line of Least Resistance in feet,

and C a coefficient to be determined by experiment, according to the nature

of the ground and the class of dynamite employed. In No. 1 dynamite the following values have served as data:—

Very solid masonry,	...	...	...	C = 0.33
Hard limestone,	...	...	...	C = 0.23
Soft limestone,	...	...	...	C = 0.15
Non-compact rock,	...	...	...	C = 0.12

Speaking generally of dynamite if—

E = the quantity of the dynamite charge in lbs., and L.L.R. as before,

then $E = C \cdot \overline{\text{L.L.R.}}^3$, where C = from .003 to .006,.....(2).

In framing estimates, it is generally reckoned that $\frac{1}{4}$ lb. of dynamite is required for every 10 cubic feet of hard rock.

Dynamite how used in practice.—In soft grounds, clay, marl, &c., dynamite is employed in the following manner: a hole is made of 1 or 1.5 inches in diameter, and 8 or 12 feet in depth, one dynamite cartridge (2 oz.) is dropped to the bottom of this hole and exploded, when it forms a spheroidal chamber; this chamber is enlarged by means of other cartridges until it can hold $4\frac{1}{2}$, 11, or 22 lbs. of dynamite, according to need, and it is then filled with the No. 3 explosive. The firing of a large charge of No. 3 dynamite should always be done by means of a cartridge of dynamite No. 1 furnished with a strong cap.

When it is desired to shatter a body by means of dynamite, it is first of all necessary to insure between the dynamite and that body a close connection, and also to multiply as much as possible the points of contact. The effect will always be greatly increased by placing on the opposite side of the substance to be shattered a resisting force, as for instance masses of stone or timber-struts.

Dynamite and powder compared.—In using dynamite, a deduction may be made as compared with powder as follows:—

	Per Cent.
For galleries in hard schist,	13
„ cuttings in syenite of medium hardness,	35
„ „ „ very hard,	43
„ „ granite,	44

It may be assumed that hand labor is diminished from 40 to 50 per cent., which represents in time a diminution of one-half.

The following table, obtained from actual experiments, will show at a glance the relative values of gunpowder and dynamite.

Explosive.	Composition.	Heat evolved in explosion in Thermal units.	Volume of gas produced per lb of explosive in cubic feet.	Product indic- ating measure of blasting effect.
Gunpowder, ...	Potassium nitrate, 74.70	1,098	8.61	3,945
	Sulphur, ... 12.45			
	Charcoal, ... 12.85			
	100.00			
Dynamite No. 1,	Nitro-glycerine, ... 75	1,780	8.56	15,336
	Silica, ... 25			
	100			

*Examples—*I. Driving a railway tunnel under Clifton Downs, Eng-land, the bore holes being drilled by machinery of the same size and depth.

Explosives used.	Distance driven in yards for- ward	No. of bore holes or shots per yard forward.	Total No of bore holes.	Weights of explosives in lbs. for every 18 yards for- ward.	At per lb.	Cost of explosives.
Gunpowder,	8	31	465	1417½	d. 5	£ s. d. 29 10 7
Dynamite,	15	17	255	165	s. 2	16 10 0

II. In the Pribram mines on the Continent of Europe, where dynamite is much used, there is a saving in using dynamite over gunpowder with electric blasting of 23 per cent. in the price per yard, 28 per cent. in wages, and 33 per cent. in time. When safety fuze and detonating caps were used, the corresponding figures were 9, 11 and 25 per cent. respectively.

Dynamite on Wood.—If it be required to shatter a piece of wood or a tree, by surrounding them simply with the cartridges, it will be necessary to employ the following charges of Dynamite No 1:—

Ounces.	In	In	In.
3.5	for a block of 4 × 4	or a tree of 4	in diameter.
8.75	" "	8 × 8	" " 8 " "
35.00	" "	12 × 12	" " 12 " "
105.00	" "	16 × 16	" " 16 " "

A large saving in the charge will be made by drilling the substance for half its thickness, and filling the hole for one-half its length. Instead of having one hole, several can be made, converging in such a way that the whole of the charges explode simultaneously by the action of one cap. Then the following charges only will be necessary :—

8.5	ounces	for a diameter of	8	inches.
8.75	"	"	12	"
24.5	"	"	16	"

Examples—

I. In 13 minutes altogether, dead tree, $2\frac{1}{2}$ feet diameter, 40 feet high, blown 2 feet into air and all roots dislodged with 1 lb. of dynamite.

II. With large tree (living), skin bark all round at root for 2 inches, encircle it with a half inch tube of dynamite, insert detonating cap and fuze, cover well with clay and explode. Tree will be severed at root with only 6 inches of wood destroyed.

Dynamite on Iron.—In order to break a rectangular piece of iron, the charge is placed on the wider side so as to occupy the whole of the width. This charge increases with the thickness in the following manner :—

For a width of 40 inches,

No. 1 Dynamite.	{	5.25 oz. with the thickness,	...	2	inch.
		1.32 lb. " "	...	4	"
		5.28 lbs. " "	...	75	"
		38.00 " "	...	2.00	inches.
		132.00 " "	...	4.00	"

Examples—

I. An ordinary double-headed iron rail can be cut by 8 ounces of dynamite placed against it (*Fig. 8*) and detonated.

II. Four ounces of dynamite with primer ($\frac{3}{8}$ oz.) sufficed to break cast-iron girder as shown (*Fig. 9*).

III. Hollow cast-iron road roller, 2 feet $10\frac{1}{2}$ inches diameter and $\frac{7}{8}$ -inch thick, weighing 478 lbs., smashed into 30 pieces with 8 ounces of dynamite.

IV. A cylindrical block of wrought-iron, $11\frac{1}{4}$ inches diameter, $12\frac{1}{2}$ inches long, and bored through the centre with a one inch hole, had its hole filled with 8 ounces of dynamite and exploded. One-half was blown 80 feet in one direction, the other half 50 feet in another, and stopped by banks. On examining the iron after explosion, the bore hole was found

to be enlarged to $1\frac{1}{2}$ inch at the centre, tapering to the original diameter at 3 inches from the ends. The bore was not plugged. The explanation of the enlargement probably was that, the explosion, although practically instantaneous, commenced at one end where a portion of the charge was exposed to the resistance of the atmosphere only, its intensity gradually increasing as it neared the centre where it reached its maximum, and as gradually declining towards the other end of the bore which was open to the atmosphere. The area of metal thus torn was 120 square inches.

Dynamite on Walls.—To destroy a wall, the best method is to place the charge at the foot to a depth equal to half its thickness, and to pack the space above tightly with stones.

Examples.—I. 18 inch brick walls can be cut by $1\frac{1}{2}$ lbs. of dynamite per foot run placed against them without any tamping.

II. *Demolition of part of the Vienna Exhibition.*—The building was of stone concrete and had stood 4 years. In first experiment wall chosen was 2·3 feet thick, and 21 feet long. Along the foot of this wall was laid a charge of 55 lbs. of dynamite in rolls, or nearly 8 lbs. per running yard, and covered with 3 feet of earth. The effect of the blast was to bring down the wall, together with a portion of another standing 8 feet away with the arches resting upon the latter, and the débris was carried a distance of 200 paces: the charge therefore appeared excessive. In the second experiment the charge was reduced to less than one-half, the effect being the complete destruction of the wall. In the third experiment the charge was again reduced from 26 lbs. to 18 lbs., which proved amply sufficient. Taking the last charge and substituting in the formula

$$L = mw^3, \dots\dots\dots (3).$$

Wherein L = charge in lbs. per lineal foot,

m = coefficient to be found by experiment,

w = thickness of wall in feet,

we obtain,

$$86 = m \cdot 2\cdot3^3 = m \times 5\cdot29$$

$$\text{Therefore } m \text{ (the coefficient required)} = \frac{86}{5\cdot29} = \cdot162$$

$$= \frac{1}{6} \text{ nearly.}$$

Dynamite on Rock.—Examples—

I. The St. John Del Rey Silver Mining Company used dynamite, and found it more effective and economical than gunpowder. Formerly the Company made its own powder and thus saved freight, duty, and inland carriage of one of its component parts, charcoal. Now they send out the dynamite at a greater first cost, and pay the freight, duty and carriage on the whole bulk, yet have saved £2,000 a year by its use. As regards its transport, the Company had no difficulty in obtaining ships to carry it at the same freight of gunpowder, or in inland 300 miles by rail as far as the railroad goes, then by waggons, and lastly on mules backs, and without a single accident during the seven years the Company has used it.

II. Large piece of hard gneissic rock $3\frac{1}{2}' \times 2' \times 2'$ shattered to bits by 8 ounces of dynamite placed on top and covered with clay, and exploded with fuze and detonator.

Dynamite in earth is not so effective as gunpowder.

Dynamite on rock under water.—Examples—

At the Lydney Harbour Works, England, in 1873, both gunpowder and dynamite were tried. The following were the objections to powder :—

- (i). It was requisite to bore 18 inches below the required depth in order to effect the displacement of the rock.
- (ii). The rock when broken came away in large pieces difficult to lay hold of with the dredger.
- (iii). The miss-fires amounted to 15 per cent., and a miss-fire always involved moving the raft from which the holes were bored slightly, and of boring another hole near the unexploded one.
- (iv). The process was slow.

The advantages in using dynamite were—(i), it was not necessary to bore the holes so deep; (ii), very little tamping was required, the 12 feet head of water being nearly sufficient of itself; (iii), the explosion was sharper and more radiating, shattering the rock, instead of breaking it into large pieces, thus enabling the dredger to pick it up with ease; (iv), there were no miss-fires, and (v), the process was quick.

The relative cost of removing 10 cubic yards of rock and placing it on shore was—

	With Gunpowder			With Dynamite.		
	£	s.	d.	£	s.	d.
Drilling holes,	0	11	3	0	7	6
Powder cartridges with fuze,	1	0	0	...		
Dynamite with detonators and wire,	...			0	13	11
Miss-fires, 15 per cent.,... ..	0	4	8	...		
Dredging 10 cubic yards,	0	15	0	0	15	0
Interest on dredger and plant, &c.,	0	3	4	0	3	4
	2	14	3	1	19	9
	or			or		
	5s. 6d. per cubic yard.			4s. per cubic yard.		

Dynamite on river obstructions.—*Examples—*

Blasting old piles, snags, &c., in Danube near Vienna.

I. Two heavy 18 inch piles of old bridge, 15 feet apart, 100 feet from centre line of existing bridge, and 400 feet from left bank, mean depth of water round them 10 feet, their heads just above mean water level, current very violent, and bed of river washed out 5 feet deep on down-stream side. Cartridge with 2·2 lbs. of dynamite made up with primer and wires in tin case, case coated with gutta-percha composition, wires being allowed to project, and secured to long wooden pole which was pushed down on the up-stream side of the pile close to the ground and fastened to the pile. Wires were also covered with gutta-percha. The electric battery was on shore. On explosion, column of water sent up 25 feet into the air, and both piles broken off flush with the ground.

II. Two heavy oak logs were found embedded in the Danube Canal, first 25 feet long with large roots, and mean thickness of 5 feet, it was lying crosswise deeply imbedded in the gravelly bed, and as usual there was a deep hole on the down-stream side and a bank up-stream. Depth of water over log 5 feet. Two tin cases filled with 13 lbs. of dynamite as before; these cases were attached to lower ends of 2 poles, which were driven into the ground on up-stream side of oak log, and 6 feet from each end: the tin cartridge cases were thus brought into close contact

with the log, and were about 18 feet apart. Firing as before. But explosion much more violent, water, gravel and débris being thrown up 33 feet. From soundings immediately taken, it was found that, not only had the logs been completely destroyed and removed, but that the bed of the Canal had been equalized, the depth of the water being now 10 feet throughout. Second log, 7 feet long and 8 feet 4 inches diameter; depth of water over root 4 feet. Dynamite charge 8 lbs. Destruction immediate and entire. Both the logs removed in $3\frac{1}{2}$ hours at a trifling cost.

EXPERIMENTS WITH DYNAMITE.

To—The Supdg. Engineer, 2nd Circle, Coimbatore.

Dated Ootacamund, 6th July 1880.

Order to conduct experiments.—With reference to Public Works G. O. No. 2686W., 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 constructions of ghaut roads, breaking up and removal of boulders from road surfaces or elsewhere, 'getting' rock for the manufacture of road metal, &c."

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 enquiry to which his attention was to be directed. Mr. Milne came to me from the Wynaad, and was at Metapolliem 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, $1\frac{1}{2}$ and $1\frac{1}{4}$ inches in diameter.

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

Experiments how recorded.—The experiments on dynamite recently conducted near Metapolliem are all recorded in the accompanying twenty-two plans and in the Record Book.* The plans and sections are drawn to a scale of 4 feet to the inch, or $\frac{1}{4}$ in. 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.

* *Editor's Note.*—The Author sent the Record Book of the 1180 charges for publication, but as that was too voluminous, a short Note seems necessary. Table No. I. is Author's abstract of the Record Book, and the first five columns have been added here to show clearly the number and nature of the charges fired, from which the totals in the abstracts have been deduced. It will be seen that the great majority of the charges are small, they were all apparently in vertical bore holes, and in the case of the larger charges, the dynamite filled up two-thirds of the bore holes, so that the line of least resistance was greater than the tamping. The specimen plan published shows the nature of the faces operated on. The bore holes were slightly

† All these remarks appear to apply to "demolition of" not "getting" rock for building purposes, see page 25.—[ED].

in excess length of the line of least resistance. The dynamite experiments recorded in Table I. were 884 : from 885 to 1086, or 152, were charges of gunpowder for sake of comparison, shown as cases No. 21 and 22 in Table I.; and from 1087 to 1180, or 144, were dynamite charges on detached rocks or boulders, of which the results are abstracted in Table II.

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,	0·13	lbs. 0·4
Lineal feet of holes bored " " "	0·84	feet 1·96
Number of men moving rock " " "	0·48	men 0·9
Lineal feet of fuze used " " "	0·70	feet 1·56

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

<i>In Dynamite,</i>		18,488 to 1
<i>In Gunpowder,</i>		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 granites, &c. Rankine also states that in gunpowder from $\frac{1}{2}$ to $\frac{3}{4}$ of a lb. of powder is generally required for each ton of rock removed; our powder experiments give 6·7 oz., or $\frac{2}{3}$ of a lb. per ton. In dynamite we see that $\frac{1}{2}$ of a lb. sufficed: and in No. 644 of the experiment books, the charge was only $\frac{1}{10}$ of a lb. per ton. Hurst gives 3 lbs. of powder to every 100 cubic feet of rock blasted: our experiments in dynamite give 1 lb. of dynamite for the same.

In the Metapoliem 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. 1·8 per lb.:—

	Gun- powder	to	Dyna- mite.
Explosive charge in weight per ton of rock removed, ...	1	:	0·5
Bore holes " " " "	... 1	:	0·3
Labor for removing rock after blasting "	... 1	:	0·6
Fuze " " "	... 1	:	0·5
Entire cost " " " "	... 1	:	0·7
Time " " "	... 1	:	0·5

Or, in other words, to produce the same effect on a mass of rock, dyna-

mite 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.

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. 1118 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 Metapoliem:—

		Dyna- mite.	Pow- der.
In every 100 cubic feet of rock blasted.	{ Rocks shattered by the dynamite and		
	{ loosened by the powder,	78	56
	{ Rock thrown out a moderate distance, ...	21	43
	{ Rock thrown out a considerable distance, ...	1	1
		<hr/> 100	<hr/> 100

and

In every 100 cubic feet of rock disturbed by the first blasts.	{ Rock which had to be re-blasted, ...	5	20
	{ Rock removable by hand,	63	20
	{ Rock removable by crowbars,	88	60
		<hr/> 100	<hr/> 100

The peculiar *percussive* effect of dynamite is well illustrated in No. 1114 of the Record Book, where the upper portion A was knocked off as it might have been by a hammer.

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.

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 re-bored and blasted, unless they are situated at a height and are blown by the explosion across the roadway 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 $1\frac{1}{2}$ to 2 times their depth. Exceptions may arise, as in section, *Fig. 10, Plate II.*, where if the piece ACB had to be removed, and $BC = d\ 4$, and $AC = d\ 6$ feet, then a 6 feet hole should be bored, and exploded with a charge for a 4 feet line of least resistance.

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 one foot. The plan and section, *Figs. 11, 12, Plate II.*, will illustrate this point. The lines in both show the cracks and clearance 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.

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. 1113, 1114, 1109, 1108, 1060, 1061, 1062, 644, in the Record Book.

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 length, 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 moderately small are preferable to a single hole of a larger diameter.

In the case of a 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. 1157 to 1173 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. 1150 to 1156, 1144 to 1147, 1124 to 1132, 1119, 1120, of the Record Book which illustrate this point.

Where a well may have to be sunk through rock, a face may be obtained by drilling three 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. 1037 to 1069 inclusive of Record Book for rock blasting in a well; and Nos. 1053 to 1056, 1060 to 1062, and 1067 to 1069 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.

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.

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. 1149, 1157 and 1172 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. 1086, 1087, 1088 and 1089 of the Record Book.

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 one ounce to every square foot of vertical section. See Nos. 1108, 1109, 1113 and 1114 of the Record Book.

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 inch 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. 1115 and 1116, and compare them with Nos. 1108 and 1118 of the Record Book.

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 débris, 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 two 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.

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.

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.

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:— $1\frac{1}{2}$ lbs. of dynamite was tied to one side of each column in a bunch, and these two charges were connected by a chain of dynamite cartridges and exploded. Four holes, two in each, were simply knocked through the two hollow columns ac-

according to *Figs. 13 and 14, Plate II.* 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 curvilinear hole about 2 or 3 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.

Dynamite tamping.—Different materials were tried in tamping the bore holes 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 the rod.

Sand was used in tamping the bore holes in precisely the same way as clay was used. With deep holes it was not 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 miss-fires, as the fuze and primer can be easily removed, and a fresh fuze and primer re-inserted. But miss-fires 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 miss-fire. 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 watertight 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 miss-fire 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.

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.

- 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.

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 caused a loss of power through the bore hole.

Miss-fires.—When a miss-fire 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 any stiff tamping is employed, in case of a miss-fire, the tamping must on no account be removed; this would involve 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, 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.

Where 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 sketch plan (*Fig. 15, Plate II.*) 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.

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 $\overline{L.L.R.}$, or in other words with the rough contents of the mass of rock to be blasted. But where the charges and the lines of least resistance 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 feet line of least resistance, and loaded numerous corresponding bore holes with various charges until one was found which exactly answered. With the co-efficient on the $\overline{L.L.R.}$ thus obtained, we calculated other charges for holes with lines of least resistance both less and greater than 3 feet. We always found that where the lines of least resistance were less than

3 feet, the charges thus calculated were too low, while with lines of least resistance 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 resistances to the charges do not vary as the $\overline{L.L.R.}^3$, 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 $\overline{L.L.R.}^3$ should also be considered, and that these affect the result much more than the mass.

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 $1\frac{1}{2}$ times the line of least resistance, or $\overline{L.L.R.}$, and that the rock will fracture evenly on the three surfaces DE, FG, GH, (plan and section, *Figs. 16 and 17, Plate II.*) shown by the 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, *Fig. 17*). 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 ,

$$\text{Then} \quad P = R^a + R^f, \dots\dots\dots (1).$$

Applying this formula to the above figures we find—

$$\begin{array}{c} \text{Area of 3 surfaces} \\ R^a = 6.5 \times \overline{L.L.R.}^2 \times r, \dots\dots\dots (2), \end{array}$$

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

$$\begin{array}{l} R^f = \underset{\text{Mass C.}}{W} \times \cos 35^\circ \text{ (angle of friction)} \\ = 2 \times 1 \times 1\frac{1}{2} \overline{L.L.R.}^3 w \times .82 \\ = 2.5 \text{ nearly } \overline{L.L.R.}^3 \times w, \dots\dots\dots (3), \end{array}$$

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

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

$$P = 6.5 \overline{L.L.R.}^2 \cdot r + 2.5 \overline{L.L.R.}^3 \cdot w$$

$$\text{or} \quad P = 2.5 \overline{L.L.R.}^3 \times \{2.6 \times r + (\overline{L.L.R.}) w\}, \dots\dots\dots (4),$$

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

Taking $w = 180$ lbs. Avoirdupois,

and $r = 432,000$ lbs. Avoirdupois,

and substituting

$$P = 2.5 \overline{L.L.R.}^2 \times \{2.6 (432,000) + 180 (L.L.R.)\}$$

$$\text{or } P = 540 \overline{L.L.R.}^2 \times \{ \overset{\text{Tearing Force}}{6240} + \overset{\text{Frictional Force}}{(L.L.R.)} \}, \dots\dots\dots (5)$$

Now the explosive charge is obviously proportional to the disruptive force P.

Taking therefore L.L.R. from 1 to 10 feet, and omitting the common factor 540 $\overline{L.L.R.}^2$ from equation (5), we obtain

L.L.R. feet.		Tearing Force due to area.	Frictional Force due to contents.	Tearing Force due to area.	Frictional Force due to contents.
Charge for 1	varies as	6240 +	1,	or as	1 + .0016
" 2	"	6240 +	2,	"	1 + .0032
" 3	"	6240 +	3,	"	1 + .0048
" 4	"	6240 +	4,	"	1 + .0064
" ..	"	&c. ..	&c. ..	" ..	" ..
and charge for 10	"	6240 +	10,	"	1 + .016
" " 100	"	6240 +	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 $\overline{L.L.R.}^2$ and to contents $\overline{L.L.R.}$. But it is believed that they accurately indicate, in calculating the required explosive charge, the preponderating influence of the former element.

That the area may the most affect one problem while the contents affects 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 $\overline{L.L.R.}^2$. But if the bore hole were drilled *horizontally* into the boulder, then the charge might be affected more by the *weight* $\overline{L.L.R.}$ than by the area, and if the mass is very large, the resistance due to the weight or $\overline{L.L.R.}$ would greatly preponderate.

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, (Fig. 18, Plate II.) 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 $\overline{L.L.R.}$ assist the ex-

plonsive 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 OBEG, because the mass assisting the fracture would be greater, while the sectional area remained very much the same. And in the example given in *Fig. 18, Plate II.*, 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 alone without any explosive.

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

$$W = A \overline{L.L.R.}^3 B + \overline{L.L.R.}^3, \dots\dots\dots(6),$$

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 *Fig. 18*, the equation would take this form,

$$W = A \overline{L.L.R.}^3 - B \overline{L.L.R.}^3, \dots\dots\dots(7),$$

but this is not at all common in practice.

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 values of the co-efficients A and B have been found by experiment on the gneiss rocks which were blasted near Metapolliem; 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.

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 Metapolliem, and is believed to be very accurate.

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 2½ ounces, and a primer ¾ of an ounce. Thus where in 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 ounces 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.	NUMBERS OF DYNAMITE CARTRIDGES.	
		No. of cartridges 5 to the lb. 3 ozs. = 1 cartridge.	No. of cartridges 7 to the lb. 3½ ozs. = 1 cartridge.
Lineal feet.	Ounces.	No. of Cartridges.	No. of Cartridges.
1	$\frac{1}{4}$	Primer.	Primer.
1½	1½	2 Primers.	2 Primers.
2	3	1 Cartridge + Primer.	1C + P
2½	5½	3 Cartridges + P.	2 + P
3	8½	4 + P	3 + P
3½	12½	6 + P	5 + P
4	17½	9 + P	8 + P
4½	23½	12 + P	10 + P
5	31½	16 + P	14 + P
5½	40½	20 + P	17 + P
6	51	25 + P	22 + P
6½	63½	32 + P	28 + P
7	78	39 + P	34 + P
7½	94	47 + P	40 + P
8	112	56 + P	48 + P
8½	133	67 + P	57 + P
9	156	78 + P	67 + P

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 L.L.R. 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 lbs.

$$\frac{\text{L.L.R.}^3}{6} \dots\dots\dots(8).$$

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 lbs. were—

$$\frac{\text{L.L.R.}^3}{10} \text{ and } \frac{\text{L.L.R.}^3}{15} \dots\dots\dots(9),$$

the former too violent the latter too weak.

At Cuxton, near Chatham, in chalk rocks rather more than

$$\frac{\overline{L.L.R.}^3}{27} \text{ and } \frac{\overline{L.L.R.}^3}{20}, \dots\dots\dots(10)$$

were the charges used in lbs.

Rankine gives in lbs. the charge for powder

$$\frac{\overline{L.L.R.}^3}{10} \text{ to } \frac{\overline{L.L.R.}^3}{82}, \dots\dots\dots(11).$$

In Table No. II. for dynamite, the charge in lbs. varies from

$$\frac{\overline{L.L.R.}^3}{82} \text{ to } \frac{\overline{L.L.R.}^3}{116}, \dots\dots\dots(12).$$

Nobel's No. 1 dynamite cartridges are from $\frac{7}{8}$ to 1 inch in diameter, $3\frac{1}{2}$ inches long, and each weighs 2 ozs. and $2\frac{1}{2}$ ozs. 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.
Inches.	Avoirdupois. Lb. ozs.	Avoirdupois. Lb. 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

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 undercharged and another overcharged, because all the holes may be considered as acting together, and generating *one* explosion: the hole that may be overcharged thus assists that which is undercharged.

The *full* lines in the sketch in *Fig. 19* show the probable line of fracture with simultaneous firing, and the *dotted* lines show the lines of fracture when the holes are exploded separately. 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 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.

Miss-fires 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 miss-fires 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 6 holes at once at a cost of Rs. 200 each.

Dynamite should supersede Powder.—In conclusion, it appears clear, from the experiments herein recorded, that dynamite ought everywhere 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 sound state.

Mr. Milne's services 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.

J. L. L. M.

Proceedings of the Madras Government, Public Works Department

READ the following :—

From the Supdg. Engineer, 2nd Circle, No. 187, dated 26th July, 1880.

Memo. by the Chief Engineer, P. W. Department, dated 12th August, 1880.

Order thereon, 28th August 1880, No. 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 2 October, 1879, No. 2686 W, has been attained, and has demonstrated superiority of dynamite as an explosive agent, well adapted for most of the operations, in which gunpowder has hitherto been employed, in execution of Public Works.

2. The report will be communicated to the Military Department for 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 P. W. 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 valuable and exhaustive report, as also to Conductor Milne for the part taken by him in conducting the experiments.

5. A sufficient number of copies of the report* will be printed for

* Without the plans use of the P. W. Department, and for circulation or detail of experiments to the several Governments named in the margin,†

† * * * * with 50 added for the general public purposes of Government.

(True Extract).

(Sd.) R. H. SANKEY, COL., R.E.,

Secy. to Govt., P. W. D.

To the Supdg. Engineer, 2nd Circle, for early communication to Major Morant, Royal Engineers.

No. $\frac{824}{W.C.}$

Communicated to Major Morant.

(Sd.) W. R. MEAD, MAJOR, R.E.,

Supdg. Engineer, 2nd Circle.

Dated 24th August, 1880.

(True Copy).

(Sd.) J. L. L. MORANT, MAJOR, R.E.



or the various conditions shown.
 For boulders by ounces to square feet of least vertical section.

		ILLUSTRATIONS.				
						
Explosive employed.	Loose detached rocks.					
	Different conditions of boulder blasting.	Vertical hole bored in detached boulder to proper depth i. e. $\frac{1}{2}$ height of rock.	Vertical hole bored $\frac{1}{2}$ height of rock in depth.	Several vertical bore holes $\frac{1}{2}$ 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.
Boulders.		Explosive charges of Dynamite in ounces <i>Avoirdupois</i> .				
Nobel's Dynamite No. 1.	Least vertical section in square feet.	One ounce of Dynamite to every 4 square feet of least vertical 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.
	are Feet.	Ounces.	Ounces.	Ounces.	Ounces.	Ounces.
	2	$\frac{1}{2}$	1	2	4	8
	4	1	2	4	8	16
	8	2	4	8	16	32
	12	3	6	12	24	48
	16	4	8	16	32	64
	20	5	10	20	40	80
	24	6	12	24	48	96
	28	7	14	28	56	112
	32	8	16	32	64	128
	36	9	18	36	72	144
	40	10	20	40	80	160
	44	11	22	44	88	176
	48	12	24	48	96	192
	60	15	30	60	120	240
	70	$17\frac{1}{2}$	35	70	140	280
	80	20	40	80	160	320
	90	$22\frac{1}{2}$	45	90	180	360
	100	25	50	100	200	400

ALFRED NOBEL'S DYNAMITE.

Skford's Fuse

FIG. 2A.



FIG. 3A.

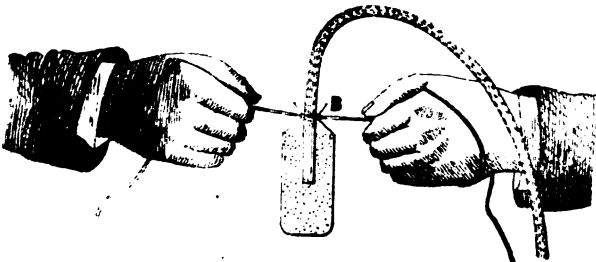


FIG. 4.



FIG. 7.

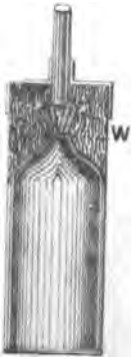
FIG. 5.



FIG. 8.



FIG. 9.



ALFRED NOBEL'S DYNAMITE.

FIG. 11.

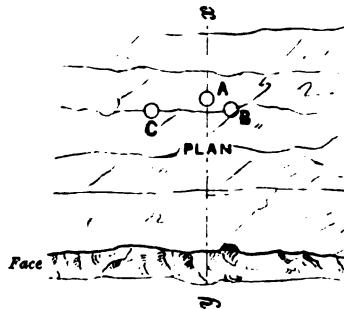
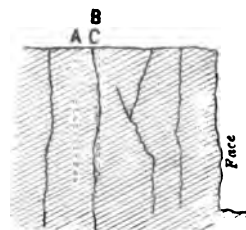


FIG. 12.



fc. 10.

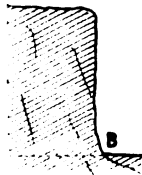


FIG. 13.

DNS THROUGH PILLARS
 HORIZONTAL SECTION
 Chain of Cartridges D

FIG. 14.

SIDE ELEVATION

FRONT ELEVATION

VERTICAL SECTION

Chain of Cartridges

1-Dynamite Charge

FIG. 15.

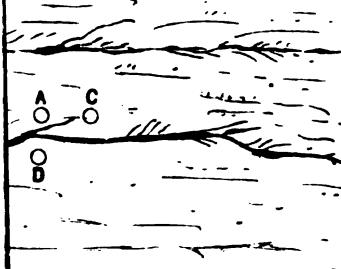


FIG. 16.

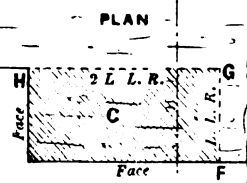


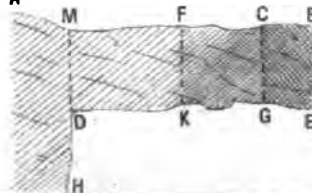
FIG. 19.

PLAN OF ROCK WITH FACE

FIG. 17.

SECTION ON AB.

FIG. 18.



Press, Roorkee.

THOS. D. BONA, *Supd*

ALF
Seal

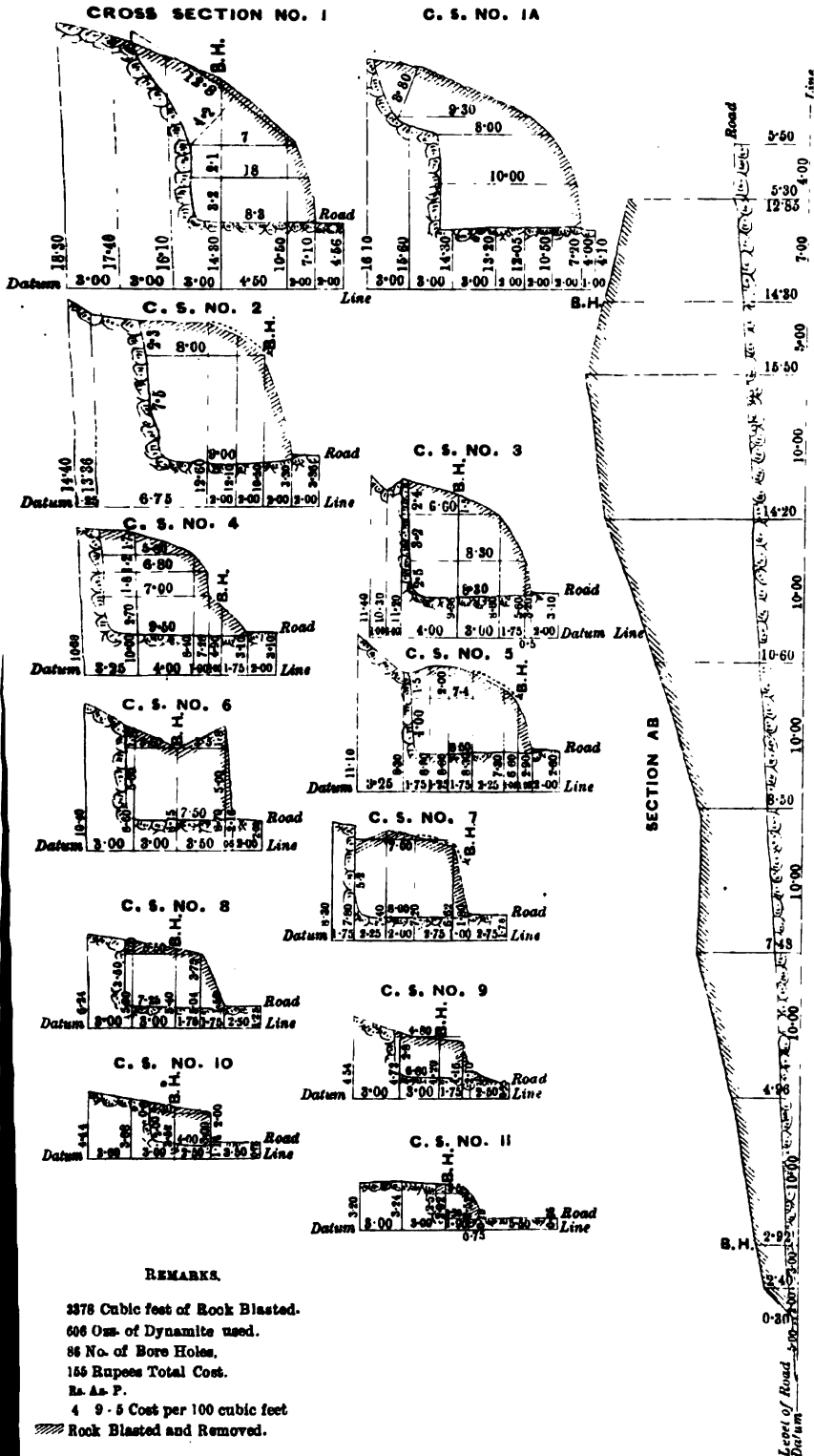
Dat

Du



ALFRED NOBEL'S DYNAMITE.

Scale, $\frac{1}{16}$ or 12.51" to an inch



1. The first part of the document is a list of names and titles.

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No. CCCXXXIII.

REPORT ON THE ULSOOR WATER WORKS.

[*Vide* Plates I.—VI.]

By LIEUT. F. J. ROMILLY, R.E., *Bac. Engineer.*

Dated Bangalore, 30th September 1879.

THE "Ulsoor Water Works" is the system by which the barracks occupied by the European troops stationed at Bangalore are supplied with water for all domestic purposes. Commenced about 18 years ago the system is now complete, (with the exception of a few minor details,) but during the progress of the work the original arrangements have been subject to many modifications, and in reporting upon the works, it is purposed to give as brief a history as possible of the project from its commencement, describing the modifications or additions to the scheme in order as they occurred.

The Ulsoor rock project, which is the basis upon which the existing scheme has been constructed, was drawn up by Lieut. H. Tulloch, R.E., (Madras) in 1862. The idea of the project seems to have been suggested by Colonel Green when discussing the Nundidroog scheme, who suggested supplying the Cavalry barracks from the Ulsoor tank, by raising water from it in four lifts of from 8 to 10 feet each, and in Lieut. Tulloch's project the Ulsoor tank was proposed as a source of water supply to the garrison. It may here be observed that a scheme for constructing a masonry sewer to carry the drainage of the Cantonment Bazaar, which up to this time had discharged into the Ulsoor tank, under and away from the tank was approaching completion, so that contamination of the

tank water by sewage matter, one of Colonel Sir A. Cotton's objections to this tank as a source of water supply, was no longer to be apprehended. The sewer was completed in 1864.

The objects which the project proposed to carry out were as follows:—

- (1). To supply water pure and fit for all purposes to all the barracks occupied by European troops at Bangalore.
- (2). To supply it in unlimited quantities.
- (3). To bring the supply within reach of every soldier.
- (4). To carry the water supply inside every lavatory, bath-room and cook-room, and arrange for its being there drawn for use by simply turning on a tap.
- (5). To provide for the storage of one month's supply at every barrack, to be kept ready for use in the event of any emergency.

Source of Supply.—Before proceeding further, it will be as well to describe the *Ulsoor tank*, the source of supply from which the project takes its name.

The Ulsoor tank is situated at the north-east end of the Cantonment of Bangalore, and is supplied by two feeders which enter the tank at its north and west extremities, the latter feeder being also the main drainage channel of the Cantonment Bazaar. The legitimate gathering ground of the tank amounts to about 3,700 acres (say 5 square miles), but about $\frac{1}{5}$ th of this, or 370 acres, is intercepted by feeders constructed to convey the drainage into reservoirs constructed by the Mysore Government during 1863-66, and situated at the western end of the valley of the western feeder. These reservoirs are intended to supply the Mysore establishments and population of the town, and form part of a project in course of execution by the Mysore Government. The gathering ground of the tank consists of red soil or decomposing feldspathic rock exceedingly porous and friable.

The following statistics regarding the effect of rainfall upon the tank and gathering ground are interesting. In 1871, 29 inches of rain fell in 32 weeks, but in 13 weeks only was there any perceptible rise in the tank noted (nothing under 0·25 inch being recorded).

The total rises amounted to 50·25 inches, or as about 24 inches were taken out for the troops during the year, say 74·25 inches for a total rainfall of 29 inches, equivalent to an average rise of 2·56 inches per inch of rainfall.

Out of the total rainfall of 29 inches, 12 inches falling in showers had individually no effect on the tank.

Five inches falling in heavy showers raised the tank 5 inches in separately appreciable quantities.

Twelve inches falling in heavy connected showers gave the tank 33 inches of rise, or 21 inches from the gathering ground, and 12 inches by direct rainfall.

The tank being taken at 124 acres, and the gathering ground at 5 square miles, the 12 inches of rain would only give .8 inch of rain as collected from the surface and as reaching the tank.

In August 1878 a rainfall of 5.75 inches in 24 hours raised the tank 2 feet 8.5 inches in the same time, equivalent to .9 inch on the catchment. Evaporation during rainy weather is at the rate of 1.2 inch per week.

The waste weir of the tank is placed at the south extremity, where the contour of the margin forms a deep triangular bay. It consists of a body wall of dressed stone with piers at 10 feet clear interval forming a bridge of 9 vents, by which the road along the eastern margin of the tank is carried over the surplus channel. The total available waterway of the weir is 90 running feet. Until 1877 the weir was provided with upright stones and shutters, by which water could, if desired, be held up to 2 feet above the (then) Cody (or Calingula crest) level. These shutters were last used in 1872. In 1877 the upright stones were taken out and laid flat on the weir crest, thus raising it 9 inches, and increasing the capacity of the tank by 21 million gallons, and also slightly increasing the waterway of the weir. The weir has a clear overfall, and the maximum head on the weir recorded is 2 feet, and the discharge with such a head would be 805 cubic feet per inch, or 68,552,000 cubic feet in 24 hours. The maximum recorded rainfall at Bangalore is under 6 inches in 24 hours, which would give 69,696,000 over the gathering ground of 5 square miles. Suppose half of this to reach the tank, which from the statistics given above is in excess of what may be expected, the weir could discharge it in less than 24 hours.

A prominent natural feature connected with the tank is the "rock," a collection of large boulders of stratified rock rising abruptly out of the tank with a steep "strike" in the middle of the eastern bund, about 400 yards north of the waste weir. The summit of the rock is about

48 feet above the crest of the weir, and on the top is a small pagoda about 10' $\times$ 10' and 12 feet high.

In August 1862, when the report on the proposed project was submitted to Government, it was stated that the area of the tank was 490,000 square yards, and in some parts 80 feet deep, while when water stood at its usual level the depth was nowhere under 8 feet. Assuming this as the average depth, the capacity was calculated to be $490,000 \times 27 \times 6\frac{1}{2} = 82,687,100$ gallons. In 1872 the tank was surveyed, and soundings taken on six sections, when it was found that the deepest part was 10.98 feet only below waste weir level. On 20th November, 1876 there was only 2 feet 2 $\frac{3}{4}$ inches of water at the deepest part, and the water level at that time being 7 feet 1 $\frac{1}{2}$ inches below cody level, the bed of the tank at its deepest part was only 9 feet 4 $\frac{1}{2}$ inches below the crest of the weir. Supposing all these figures to be correct, they show that between the years 1862-1872 the deepest part of the tank had silted up 19.02 feet, and 1.56 feet between the years 1872-1876. It seems impossible, however, that the bed could have silted up 19 feet in 10 years, and it is more probable that the depth of 80 feet assigned to the deepest part in 1862 was overstated by mistake. In the early part of 1877 when the tank was quite dry, numerous and careful measurements were taken, when the following data were deduced :—

Area of tank	= 124 acres.
Average depth	= 7.68 feet.
Greatest „	= 11.85 feet.
Cubical content	= 41,501,008 cubic feet,
Capacity	= 259,381,302 gallons.
	= 260 million gallons say.

When these measurements were made the weir crest had been raised as stated above, so that the capacity of the tank with the original crest level would be 239 million gallons, nearly three times as much as what was assumed in the report of 1862.

During the late famine in 1876-77 when the tank was quite dry, advantage was taken to remove the silt and improve the tank. A road bund already existed along the south-east and north margins, and the bed was deepened, and a road bund formed along the western margin also.

With a view to check the deposit of silt brought down by the feeders,

it was proposed that the north portion of the tank at the tail of the north feeder traversed by the north bund or roadway should be converted into a silt trap or settling basin, and that the new bund on the west should be so aligned near the western corner of the tank as to form a second settling basin at the tail of the western feeder. Both proposals were carried out, but the former one was still further developed. It was ascertained that the capacity of the tank could not be increased by further raising the waste weir, as a portion of the cantonment immediately above the waterspread of the tank would thereby be flooded. It was accordingly determined to supplement its supply by constructing a subsidiary reservoir across its northern feeder, (in other words by increasing the capacity of the settling basin mentioned above,) in which drainage could be impounded after the Ulsoor tank had been filled, and used subsequently to replenish the tank. This reservoir was constructed as a famine relief work. A bund has been thrown up along the north side of the road traversing the north end of the tank, provided with a waste weir 62½ feet long of dressed stone with an ogee apron, and fitted with a vent at one end 18" × 24", closed by a shutter for passing water to the tank when necessary. The crest of this weir is 5 feet 4 inches above the crest of the Ulsoor weir. The valley above the new tank has an area of 1,130 acres, from which a run off of 6 inches in the year may be calculated on giving a supply of 35,000,000 cubic feet. The capacity of this subsidiary reservoir is 10,000,000 cubic feet, or 62,500,000 gallons, very nearly one-quarter the capacity of the Ulsoor tank.

The bunds of the tank are of good section throughout, the north-east and south banks being metalled, forming part of the Cantonment roads. The south and a portion of the east road bunds are low, and should be raised, water standing 2 feet on the weir crest would probably wash over them. The east bund from the escape to the rock and 300 yards beyond it is revetted with a rough stone wall and parapet on the tank side.

In 1862, when the Ulsoor rock project was being worked out, samples of the tank water were compared before and after filtration with the Madras waters of Egmore and the seven wells, a comparison that was favourable to the Ulsoor water, and showed that its principal impurities were iron and silica, the latter being almost, if not altogether, insoluble, and giving the water a muddy appearance. The presence of iron would

render the water beneficial on sanitary grounds, and the silicates are the very portions that would be removed by mechanical filtration. This was proved by filtering the water through 6 inches sand, 6 inches charcoal, and 6 inches gravel, when it came out perfectly clear. The total residue, organic and inorganic, was 30·2 grains per gallon as compared with 41 grains, and 98·4 grains per gallon in the Egmore and seven wells waters respectively. In 1863 a sample of the water was sent to Assistant Surgeon Nicholson, R.A., at Calicut, for analysis, who found that the water contained chlorides of sodium, carbonates of lime, magnesia, silica, and alumina, with a little iron and organic matter. It may here be noted that at the time that Assistant Surgeon Nicholson made this analysis, he was not aware of the source whence the sample of water sent to him for examination was taken.

About 1868 the tank water seems to have obtained a bad reputation, and in a G. O., dated 12th December, 1870, it is stated that "the water of the Ulsoor tank even after filtration is unfit for drinking or culinary purposes." This change of opinion regarding the fitness of the tank water for supply to the troops would seem to be the result of a report by the Chemical Examiner upon some samples of the Ulsoor tank water bottled by the President of the Municipality, and sent to Madras for examination. The bottles arrived with their contents in an advanced state of decomposition and stinking abominably, so that the Examiner came to the conclusion that the tank water contained faecal matter. This report caused a complete revolution in the execution of the water supply project then in progress, which will be described further on.

In 1871 and 1872 by the orders of Government, a very careful and complete analysis of the Ulsoor tank water was conducted by Assistant Surgeon Nicholson, R.A., at Bangalore, whose investigations and reports were further verified and commented upon by the Chemical Examiner and Sanitary Commissioner. The conclusions arrived at were that the tank water contained no faecal matter, and after filtration was perfectly wholesome and fit for drinking purposes. The water was found to deposit on standing the small quantity of very fine clay and sand which renders it opalescent. The small amount of chlorine, the total absence of nitric and nitrous acids and ammonia showed the water to be free from mineral remains, which would evidence any former sewage contamination, and the amount of organic matter present was found to be very small.

The suspended matter, besides the sand and clay noticed above, consisted also of confervæ vegetation, which, when ripe, agglomerates into a green scum, and which when blown into corners of the tank is liable to ferment and evolve the disagreeable smell peculiar to sea and fresh water algæ. It was the presence probably of some of this green scum in the samples of tank water sent to the Chemical Examiner for analysis about 1868 that led to the idea of faecal contamination of the lake water. The confervæ being a highly nitrogenized substance, would, in decomposing, resemble in colour and smell decomposing sewage matter, and in the absence of additional evidence, would very naturally be mistaken for such. It is worthy of note that the analysis of the tank water made by Dr. Nicholson in 1871, compared with his analysis of the same water in 1863, showed that the water had improved since the first examination was made. His analysis in 1871 showed greater freedom from chlorides and organic matter, probably due to the working of the main sewer which had been constructed in the interval, and to greater care in the arrangements for diverting suspicious drainage from the tank. The comparative freedom from organic matter speaks well for the conservancy Cantonment Bazaar, the surface drainage of which passes into the tank by the western feeder. The mineral characteristics of the water were the same as observed in 1863. The living organisms found in the water were trifling, some water fleas and infusorial animalcules.

The Ulsoor Rock Water Supply Project.—The details of the project may be stated briefly thus—

The source of supply was to be the Ulsoor tank, the rock was selected for the site of the head works.

The water was to be drawn from the surface of the tank at its deepest part, which is immediately opposite the rock, by a steam engine erected on the rock, at about 10 or 12 feet above high water level. The tank water was first to be pumped into four settling beds, each capable of holding three days' supply for the troops, so that 12 days would elapse before clear water was drawn off from any one settling bed. From the settling beds clear water was to be pumped up by the same engine to a large filter erected on the top of the rock, capable of filtering three days' supply in 24 hours. From this filter the water was to be conveyed by gravitation by earthenware mains to service cisterns, each capable of holding a month's supply for the barracks at which they were severally

erected. From these cisterns the water was to be conveyed by distributing pipes to each lavatory, bath-room and cook-house, and all other places where it might be desirable. Drainage pipes were to be laid down to carry off refuse water into existing drains. It may be observed that the successful working of this scheme depends upon the summit of the rock having a command of about 10 feet above the planes of site of the various barracks.

The European force stationed at Bangalore being as follows :—

- 1 Regiment of Cavalry.....A,
- 1 " Infantry.....B,
- 1 Battery Horse Artillery C,
- 2 Batteries Field " D,

the number of souls (including women and children) and horses to be supplied would be for

A.	1,200	souls and	800	horses.
B.	1,200	"		Nil.
C.	400	" and	800	horses.
D.	200	" and	150	"
<hr/>				
Total,	...	3,000	" and	1,250
<hr/>				

The daily demand was fixed at 10 gallons per head and 8 gallons per horse, and the daily consumption at the several barracks would be by the

					Gallons.
Cavalry,	...	...	...	...	18,400
Infantry,	...	...	...	...	12,000
Horse Artillery,	...	...	...	...	3,200
Field "	...	...	...	...	6,400
<hr/>					
Total,					40,000
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Allowing 50 per cent. for waste, the daily supply to be allowed was fixed at 60,000 gallons, which required a monthly supply of 180,000, and a yearly supply of 2,160,000 gallons.

This estimate showed that the source of supply was practically unlimited, the capacity of the tank being shown in page 4 to be 260,000,000, equivalent to more than 10 years' supply on the above demand. It is noted in the above data that the requirements of the native followers of the troops were not taken into account.

The estimated cost of this project was Rs. 72,000, but the estimate included amounts for the construction of plunge baths and lavatories, which are only indirectly connected with the project for water supply. Neglecting these items, the actual estimated cost of the works necessary to collect and supply water to the European troops was as follows :—

					Rs.
1 Main filter,	...	...	...	...	12,000
4 Settling beds,	...	...	...	...	6,000
4 Service cisterns,	...	...	...	...	19,000
1 Engine and pumps,	...	...	...	...	9,000
1 Engine house,	...	...	...	...	5,000
Earthenware mains,	...	...	...	...	5,000
" delivery pipes,	...	...	...	...	1,000
Cocks,	...	...	...	...	1,000
Sundries,	...	...	...	...	2,000
Total Rs.,					60,000

The Engine.—A 12 horse-power (nominal) engine with pumps had been indented for in August 1859 for raising water from the fort ditch at Madras, and had been shipped from England in May 1861. As it was not likely to be required for some time at Madras, it was assumed that it would be immediately available for the Ulsoor water works.

The force pump of the engine was to be placed one foot above the high water level of the tank, and in a most unfavourable season it was assumed that the water might fall 12 feet below this. The top of rock being 44 feet above high water level, and the bed of the filter being placed 5 feet above this again, and the depth of water to be maintained in the filter being 6 feet, the total lift would be $12 + 44 + 5 + \frac{9}{2} = 64$ feet.

The capacity of the filter as elsewhere stated was to be 160,000 gallons, which would have to be pumped up daily. In anticipation that contingencies might arise to increase the demand, such as an addition to the Military force at Bangalore, or future extension of the works to supply the town, it was assumed that the engine might be called upon to pump up as much as 200,000 gallons daily. Supposing the engine to work eight hours a day, and the unit of horse-power to be 33,000 foot lbs. per minute, and one gallon of water to weigh 10 lbs., the horse-power required is $\frac{200,000 \times 64 \times 10}{33,000 \times 60 \times 8} = 8.08$ horse-power. Allowing 25 per cent. for loss

of power in pumps owing to inferior power in fuel, imperfect superintendence, &c., about 10 horse-power would be required. The 12 horse-power engine proposed to be used was, therefore, ample for the requirements of the project or for possible future requirements.

The Filter.—The filter was to be placed on the top of the rock. In order to keep the cisterns at the barracks constantly full, and to provide against leakage, evaporation, waste, the principal filter would have to be capable of supplying three or four times the estimated daily consumption. Experience at the Howrah Water Works in Bengal showed that 30 feet super of filtering media will filter 1,000 gallons in 24 hours. The filter was designed with an area of 4,800 square feet, and was to have a depth of 6 feet when full. This would hold $4,800 \times 6 \times 6\frac{1}{2} = 180,000$ gallons, and filter daily $\frac{4800}{30} \times 1,000 = 160,000$ gallons, providing therefore an ample supply of pure water. To adapt the filter to the form of the summit of the rock, it was designed in the shape of an irregular pentagon, divided into two parts by a cross wall, so that either part could be cleaned or repaired without interrupting the daily supply, each part being capable of holding 80,000 gallons. The following is a brief description of its proposed construction.

The walls were to be built of brick in hydraulic mortar throughout, the inner faces vertical, the outer faces with a uniform batter to the bottom of the foundations, the latter being built without offsets. After the walls were constructed, stiff clay was to be thrown in and well puddled to bring the surface of the rock enclosed to the level of the highest point of the rock. Above the clay a layer of concrete one foot thick, next a flooring of best pottery clay bricks on edge without mortar supporting another layer of bricks laid flat. Above these 6 inches of coarse stone and gravel, and 6 inches of fine stone and gravel. Next 12 inches of animal and vegetable charcoal, and finally 12 inches of fine sand covered with a thin layer of clay to prevent the sand being disturbed by the water passing into the filter. The total thickness of filtering media was 3 feet. To allow of the escape of air, an accumulation of which below the filtering media has sometimes been known to hamper the action of a filter, it was proposed to erect bamboo air shafts at intervals.

The Cisterns.—There was to be a cistern at each barrack, four in all, each capable of holding one month's supply, and each divided into two

compartments by a cross wall to allow of repairs being carried out without entirely stopping the supply. There are none of the original plans in the office for me to refer to, but it would appear that they were designed by Lieut. Tulloch with walls and foundations of brick in hydraulic mortar, with a flooring of brick 6 inches thick over a layer of concrete 12 inches thick. The chief feature in them was an arrangement for promoting a current in the water, and preventing stagnation, by cross walls at intervals of 25 feet with arched openings at the alternate ends, so that water entering the cisterns at one end would have to flow in a zig-zag course to pass to the outlet pipe at the other end. The cisterns were not provided with roofs.

The Mains.—These were to be 8 inches earthenware socket pipes, placed 3 feet below the surface of the ground. It was calculated that the greater part of the pipes would not be subjected to a pressure of more than 15 feet head of water. About 600 yards would have to bear a pressure of about 50 feet. This was considered well within the limits of what earthenware pipes could bear, pipes of this material having been used in France with a head of 150 feet, and ascertained in England to burst only under a pressure due to 1,500 feet. The joints were to be packed with asphalte, or cement of 5 lbs. of cast-iron filings to 2 ounces of sal ammoniac.

In working out the project, it was found that the site of the old Dragoon barracks (now occupied by the European Infantry) was higher than the top of the Ulsoor rock. To obtain the required command, it was proposed to utilize the small pagoda on the top of the rock, situated within the site for the main filter, and to convert it into a small auxiliary reservoir on a higher level, into which the filtered water required for these particular barracks could be pumped by the engine, and gravitate to the barracks. The pagoda it was understood was no longer considered sacred or resorted to by the natives.

Sanction of the Project and commencement of the work.—The above project was sanctioned by Government on 12th February, 1863, and work in connection with the scheme commenced in April of the same year.

The cisterns at the Royal Horse Artillery and Royal Artillery barracks and new Cavalry barracks during 1863-65, but in carrying out the work considerable modifications seem to have been made on the original designs prepared by Lieut. Tulloch, viz., by the omission of the cross walls to

ensure a free circulation of water, the use of ordinary in place of hydraulic lime, and the substitution of stone for brick in the foundations and basements. These deviations appear to have been sanctioned by the Superintending Engineer on the proposals of the Executive Engineer in charge of the work. The substitution of stone in the foundations was suggested, owing to a difficulty in obtaining good table moulded bricks readily.

In March 1865 Lieut. Tulloch, R.E., who assumed charge of the Division, called attention to these deviations from his original design. He pointed out that stone is seldom used in the walls of reservoirs, as cement does not bind properly with it, and as this material was introduced at the bottom of the wall, where the pressure is greatest, he expressed his opinion that the cisterns when filled would leak.

First revision of the Project.—Up to the end of August 1864 the total expenditure on the original project was Rs. 23,738, and in September of that year a revised estimate was submitted by Lieut. Pennycuik, R.E., amounting to Rs. 1,46,300, or more than double the original estimate. The main idea of the revised project was identical with that of Lieut. Tulloch's original scheme, viz., to supply the barracks with water drawn from the Ulsoor tank, and pumped into a filter on the top of the rock, to descend thence by gravitation to the cisterns at the barracks, but the following modifications on the original estimate were introduced :—

- (1). Cast-iron piping was substituted for earthenware in the mains, and a 9-inch main was provided instead of an 8½-inch, on account of the sizes of castings in the market.
- (2). Lead piping was substituted for earthenware for minor distribution, and this was further extended to detailed house service in married quarters in lieu of the stand cocks proposed by Lieut. Tulloch.
- (3). Alteration in the arrangements of the cistern at the old Dragoon barracks, which needs description.

It had been found that not only would the floor of the proposed cistern here be 8·86 feet below the floor of the filter at the rock, but that it would be in some cases as much as 8 or 9 feet below the floors of lavatories in the barracks which it was to supply. Lieut. Tulloch, it will be remembered, foresaw this difficulty, and proposed to meet it by means of an auxiliary cistern on the pagoda on the Ulsoor rock. The idea, however, would not seem to have been regularly worked out in detail in

the original project, and it was found subsequently that not only was the pagoda far too small to allow of a reservoir of suitable capacity being erected on it, but also that the natives did regard it with veneration, and objected to its being meddled with.

Lieut. Pennycuick proposed to overcome the difficulty by having a double cistern at the Infantry (old Dragoon) barracks, one with its floor 6 feet below the ground, to be filled by gravitation from the filter on the rock, and a second one of similar capacity close by with its floor raised 10 feet above the ground level, so as to command the barrack buildings, and to be filled from the lower cistern by a local wind engine. Lieut. Pennycuick also called attention to the flooring of the cisterns already built, and which appear to have been constructed of concrete, covered with a layer of earthenware slabs 6 inches thick. He expressed his opinion that this flooring was too slight, and provided for granite stone flooring set in asphalt in the cisterns designed by him, and suggested its adoption in the other cisterns also.

A slight alteration was introduced in the nature of the filtering material. In the original project it was specified that animal charcoal was to be used as well as vegetable. The contractor who provided the material mixed human bones with the bones collected for obtaining charcoal. This was condemned by a Medical Committee assembled to consider the subject, and to prevent the recurrence of such an evil, the use of vegetable charcoal exclusively was decided upon.

As previously stated, the revised estimate amounted to more than double the original scheme as first proposed by Lieut. Talloch. The excess was due mainly to the substitution of cast-iron and lead for earthenware piping, the greater extent of minor piping owing to the more elaborate minor distribution, and the alteration in the arrangements to the cisterns at the Parade (Dragoon) barracks.

At the time that the revised estimate was submitted, the following was the condition of the work :—

The engine house was nearly complete, its progress had been delayed by difficult blasting. The engine driver's quarters were complete. The brickwork of the filter on the top of the rock was complete to floor level. The brickwork of the Royal Horse Artillery and Royal Artillery cisterns were complete, the flooring remaining to be done. The foundation and basement of the Race Course barracks cistern was complete.

Second revision of the Project.—I am unable to trace from the records in the office what orders were passed upon this revised estimate submitted by Lieut. Pennycuick, but it would appear that it was partly carried out, as in April 1865 the flooring of the filter on the rock was completed, and the cistern below ground level at the old Dragoon barracks built. As regards the difficulty of obtaining a proper command over the buildings in the Parade barracks by means of the filter on the top of the Ulsoor rock, the suggestion for overcoming this difficulty by the double cistern and wind engine at the Parade barracks proposed by Lieut. Pennycuick was not approved by Government, and the whole scheme was recast and took its present shape.

The filter on the top of the rock was abandoned, and it was determined to pump the water from the tank into a filter at the foot of the rock, to pass from thence by gravitation to a pure water basin close to the filter and at the edge of the tank, whence the same engine was to pump the pure water up to a stand pipe on the top of the rock, of sufficient height to command all the buildings to be served, and from which it would flow to the cisterns already built. The settling beds were omitted from the arrangements. These arrangements have been carried out, and are now in force. The necessary works appear to have been commenced before the plans and estimates for them were completed.

During 1865-66 the engine and pumps were set up, and the engine house built, the filters and pure water basins were commenced, and completed in the following year, when the pipes, valves, &c., were received from England.

The laying of the pipes to the cisterns on the old race course was completed by May 1868, but on testing them they were found to leak at the joints to such an extent that it was necessary to take them up and relay them. In relaying them the following precautions were adopted to ensure the joints being water-tight. The pipes were laid in lengths of about 100 yards at a time, the joints being left uncovered, and each length tested by closing the free end of the piping, and then pumping in water until a jet of water appeared at the top of the stand pipe. The joints were carefully examined during the test, and any found to leak replaced before another length of piping was laid and similarly tested.

Failure of Cisterns and Filters.—In November 1868 the cisterns at the Royal Horse Artillery and Cavalry barracks were filled, but at the

first attempt to deliver the water, although all the piping was found to be water-tight, the cisterns themselves showed signs of giving way, and pumping had to be stopped. The Superintending Engineer in reporting upon this failure expressed his opinion that the thickness of the cistern walls and the depth of the foundations was insufficient, but as the cisterns began to leak before they were half full, the immediate cause of failure was to be attributed to bad work in the flooring.

To remedy this defect it was proposed to remove part of the flooring, and to excavate a trench 12 inches broad, carried down to 12 inches below the toe of the walls inside, and to fill this with concrete, to cover the existing floor with 12 inches of masonry (brick or tile) set in partially hydraulic lime, the ends of the new floor to be curved up at the junction with the walls, to carry this masonry up to the top of the walls for a thickness of 9 inches, and to plaster the whole with Portland cement.

The filter at the foot of the rock was also found to leak, and similar remedies were proposed to be carried out to repair it.

The cost of these repairs was estimated at Rs. 84,000, and an additional height to the walls of 18 inches was given to make up for the diminution of their capacity by the interior lining and extra thickness of floor. It was proposed to carry out the repairs first to half of the cistern at the Royal Horse Artillery barracks. This cistern was selected for trial, as its southern half rested on a basement $4\frac{1}{2}$ feet, so that any insufficiency in the proposed method would be more likely to become apparent from the failure of the flooring on the deep filling in of the basement. The repairs to this half cistern were completed, and the cistern filled on 7th May, 1870, when no leakage was apparent.

The measures proposed having met with success in this case, the same method was sanctioned for the remaining cisterns and the filter, and with the following results. With the second half of the Royal Horse Artillery cistern, as with the first, they were successful, and also in the case of one-half of the cistern at the Cavalry barracks and half of the filter. In the case of the second half of the Cavalry cistern and the filter the repairs failed utterly. The work of the new flooring was found to be of excellent quality, the cement being so hard that it turned the point of the pick used in cutting out the masonry to examine the cause of failure, and the failure was attributed entirely to the excessively bad quality of the old flooring, which gave way under the weight of the water

pumped into the cistern and filter, together with the unsuitable nature of the earth used in filling in the basement.

The old flooring of the Cavalry cistern was composed of 6 inches of concrete laid upon the made earth with which the basement of the cistern was filled in. On the concrete was laid a flooring of stone set in mortar, and pointed with asphalt. On examination it was found that the new floor of two course of brick-on-edge laid in cement diagonally and plastered had sunk in several places, owing to the subsidence of the made earth under pressure. The water passing through the cracks in the new floor at these places had increased the evil, by reducing the earth in the basement to a state of pulp.

The same description applied to the floor of the filter where the sinking took place at the point where there was the greatest depth of made earth. It may be observed that the filter is built on the bund of the tank, which circumstance doubtless added to the possibility of failure. Upon the report of this failure Government decided that the capacity for storage was not required to be so great as when the cisterns were first designed, and that the second half of the Race Course barracks cistern should be left as it was, but that measures must be taken to repair the filter.

Third revision of Project—Dhobies' Wells.—Up to 31st March, 1869, the total expenditure on the project was Rs. 1,55,665, and in May of that year a revised estimate was submitted by Captain Wood, R.E., for Rs. 2,65,000 for completing the scheme on the modified arrangements already noted, and with a further modification on Lieut. Pennycuik's project by the substitution of stand-cocks at convenient positions for house supply in place of the detailed distribution to individual quarters. This estimate provided for a supply of water from the Ulsoor Tank for ablutionary and non-culinary purposes only, as in July 1868 it had been decided that even after filtration the water from the Ulsoor tank was unfit for drinking.

At the time when this revised estimate was submitted, the condition of the work was as follows :—

Engine erected, filters, fresh water basin and cisterns complete, except that for the Parade barracks. Main lines of piping laid to cisterns and east gate of European Infantry barracks, and distributing pipes to Royal Horse Artillery and Race Course barracks. To complete the work, it was required to add verandah to engine house, enlarge quarters, com-

plete main to Parade barrack cisterns, and to complete the distributing arrangements.

With this estimate were also forwarded designs for floating covers to the cisterns and pure water basin. This was considered necessary to preserve the water from pollution by bones and impurities dropped in by vultures and other birds, as well as to preserve it from vegetable growths induced by exposure to the direct action of the sun. These covers consisted of corrugated iron sheeting carried on timber purlins 4" x 4" at 5 feet interval, supported on square buoys 2' x 2' x 2' of $\frac{1}{8}$ sheet iron, strengthened and put together with angle irons, and placed at 9 feet central interval. They, however, were not sanctioned.

Owing to the unfavourable reports upon the tank water in July 1868, Government purchased the Dhobies' wells for the purpose of supplying the troops with pure water for drinking and culinary purposes, and directed the preparation of estimates for a scheme for pumping water from these wells to the barracks.

To the east of the tank, about 300 yards north of the rock and 80 yards in rear of the bund, were a number of wells, originally seven, situated in what was called the new Dhobies' ground.

These wells appeared to be fed by percolation from the tank through the bund, which takes place more or less along the whole line of bank on the south-east from the waste weir towards the north. The percolation is moderate towards the south-west part, where the soil is clay or disaggregated gneiss, but abundant at the north-east end, where a triangular bed of ferruginous gravel about 200 yards wide allows the water to filter very freely. The line of demarcation of this gravel bed is well defined. It extends well into the new Dhobies' ground, and the water in the wells stands at 5 or 10 feet from the surface according to the ground in which they are sunk being within or without the gravel bed.

All over this gravelly patch of ground water stands at a level of about 6 feet below the surface of the water in the tank, falling regularly with it.

Observations for 18 weeks, from 1st January to 29th April 1871, showed that the fall of water in the wells was nearly always identical with the amount of fall in the tank, the fall in the wells being, as a rule, about one inch more, and the difference never more than two inches.

The water derived from these wells was excellent, but on this point more will be said hereafter, and it is sufficient now to state that at this

period of the work it was considered to be fit for drinking and culinary purposes.

In June 1869 plans and estimates were submitted for three projects for supplying the troops with water from these wells for drinking and culinary purposes.

In place of a single reservoir in the water-bearing stratum from which to draw the supply, it was decided to increase the area of the wells by sinking a number of separate wells, and connecting them by masonry driftways, by which a number of small reservoirs would be obtained, which could at a moderate cost be covered in, so as to preserve the water from the action of the rays of the sun.

The estimates provided for increasing the number of wells to 16.

In Project A it was proposed to draw the water from the wells, and pump it up to a stand pipe on the Ulsoor rock, whence it would descend to the cisterns at the barracks.

In Project B it was proposed to pump the water into an iron cistern constructed on the top of the rock, capable of containing the whole supply for the barracks.

In Project C it was proposed to pump the water into a stand pipe at the site of the Dhobies' wells, and thence to cisterns at the barracks.

The object of this scheme was, as before stated, solely to supply the troops with drinking water, and it was to be kept entirely distinct from the Ulsoor rock arrangements.

The demand for culinary purposes was estimated at 5 gallons per head per diem, and the number of souls to be supplied was estimated at—

Cavalry and Artillery at Race Course barracks,...	...	1,200
Royal Horse Artillery,	...	250
Infantry,	...	1,200
Total,		<u>2,650</u>

requiring for drinking a daily supply of 13,250, or say 100,000 gallons per week, which would be distributed to the barracks in the proportion 45,000 gallons to the Cavalry and Infantry barracks, and 10,000 to the Royal Horse Artillery. This required a discharge of 90 gallons per minute at the latter barracks.

The dimensions of the pipes were calculated by Neville's formula, and assuming the stand pipes to be constructed so as to give a head of 20

feet above the highest point to be supplied, viz., the Infantry barracks cistern, it was found that a $4\frac{1}{2}$ -inch pipe was required in all cases except for the Royal Horse Artillery cisterns, where a $2\frac{1}{2}$ -inch pipe was sufficient in projects A and C. In project B $3" \times 1\frac{3}{4}"$ piping was found sufficient.

The cisterns were to be of wrought-iron, those at barracks being raised 20 feet above the ground on cast-iron pillars, and the single cistern at the rock to be 42 feet above the top of the rock. The objection to the project of the single cistern at the top of the rock in place of separate service cisterns at the barracks was, that the whole of the water would have to be raised 40 feet above the rock, while it was only necessary that the quantity required by the European Infantry, viz., 45,000 gallons, should be so raised. The advantage of this arrangement would have been the possibility of a more economical distribution of the water, as the amount to be delivered could have been regulated carefully and waste checked.

In projects A and C stand pipes were provided, in the former case on the rock, in the latter case at the Dhobies' wells. With a stand pipe at the rock, which would have to be 42 feet high, there would be loss of power, water having to be delivered at the stand pipe at the distance of 1,800 feet from the engine house at the Dhobies' wells. A stand pipe at the Dhobies' wells would have to be at least 100 feet high to obtain the required command, and the difficulty of erecting and maintaining such a pipe would probably be of greater consequence than the loss of power experienced in the other case.

The minor distribution in all three projects was practically the same, viz., by stand cocks or water houses at suitable points in the barracks.

The cost of the three projects was nearly the same, viz.—

						Rs.
For A,	...	...	...	...	...	1,84,700
" B,	...	...	...	...	...	1,83,000
" C,	...	...	...	...	...	1,86,500

No provision was made for supply to the old Foot Artillery cistern, as the old Foot Artillery barracks were abandoned about this time, and a supply there not required.

The work in connection with the Ulsoor rock project was sufficiently advanced to allow of the Royal Horse Artillery and Race Course barracks being supplied from them with water for ablutionary and non-culinary purposes from January 1871.

The projects when first received by Government were laid aside in consequence of the magnitude of the estimates, and the state of the Imperial finances. An engine and pumps were, however, despatched to Bangalore, and an entry made in the Budget, and accordingly 16 new wells were sunk and connected, and the engine house and chimney built. The work being so far advanced, in G. O. 1278 of 18th May, 1870, Government directed that the work should be carried out as simply as possible, to provide for a supply for two days consumption of drinking water.

In September 1870 the Superintending Engineer proposed to connect the Dhobies' wells with the existing piping of the Ulsoor rock project, and to pump into the cisterns to test the yield of the wells. Government objected to any arrangement by which the water from the wells could be exposed to contamination with that from the tank, and in December 1870 as ordered, a revised scheme, differing only in minor details of distribution and in fixing the supply at 3 gallons per head from that sent in June 1869, was submitted. It provided for carrying out the arrangements for completing the supply of water for non-culinary purposes from the Ulsoor rock scheme, and for a separate service for drinking water from the Dhobies' wells.

Result of working of Ulsoor Project.—During the period that the water from the Ulsoor project had been in use, it was found that an average of 80,000 gallons per day had been used by

Horses,	...	...	...	...	...	...	...	780
Troops and families,	...	...	...	...	...	...	...	1,300
Native followers,	...	...	...	...	...	...	...	2,150
								<hr/> 4,230

being an average of about 7 gallons per head. But assuming 12 gallons per day expended on each horse, there remained about 21,000 gallons left as expended by the troops and their followers, and supposing the latter to use 1 gallon a day, the consumption by the troops would be 14 gallons per head.

The cistern at the Infantry barracks was designed on this data to contain about 7 days' supply. Owing to the unsuitability of the levels of the ground, the cistern had to be built in the Bakery square at the western end of the Parade barracks, which involved an extra expense of Rs. 6,950 for piping, which would otherwise have been spared.

Amalgamation of the two schemes.—The two schemes were now amalgamated under one head, and the total cost of the combined scheme came to Rs. 3,07,400, for which the troops and horses were to be supplied with 14 gallons per head for non-culinary purposes from the Ulsoor tank, and 3 gallons per head for drinking from the Dhobies' wells. The latter allowance could be increased if the wells were found equal to the strain.

Suggestions by Sanitary Commissioner.—In May 1871 the Sanitary Commissioner, after visiting Bangalore and inspecting the water supply, suggested the possibility of the Dhobies' wells being able to meet the demand for all requirements both for ablutionary and non-culinary purposes. Should this prove to be the case, he further suggested the probability of Government being able to dispose of the water works and plant of the Ulsoor project to the Municipality.

Experiments on capacity of Dhobies' Wells.—Acting on this suggestion in May 1871, the yield of the wells was ordered to be tested, and pumping experiments were carried out from 20th to 26th May. It had been ascertained that not more than 35,000 gallons daily is used by the troops, and the actual amount pumped out during the six days was 330,000 gallons, or about 116,000 gallons in excess of what the troops would have consumed in the same time. At the end of the sixth day, however, the wells were nearly drained dry, only 2½ feet of water remaining in them. It was found during the experiment that a considerable quantity of water filtered into the wells while pumping was going on. The experiment showed conclusively that the capacity of the present number of wells was amply in excess of the requirements for culinary purposes only. Also the least amount filtered in daily during pumping was 17,000 gallons, and during the night 8,000, a total of 25,000 gallons per day, or 10,000 gallons less than the assumed expenditure of 35,000 gallons. The wet perimeter of the 16 wells was about 500 feet, and therefore to allow of 35,000 gallons being filtered in daily, the perimeter should be $5,000 \times \frac{35,000}{17,000} = 1,000$ about, or the number of wells should be doubled.

A table of the detail of the experiment is attached, which will explain the results better than any description.

By G. O. 1933, dated 22nd July, 1879, Government directed the submission of two estimates, one for the completion of the supply from the tank,

and one for completing arrangements for supply entirely from Dhobies' wells, to include 16 additional wells and new steam engine and pumps.

Conclusions arrived at after careful analysis of the tank and well water.—The analysis of the tank water made in 1871 has already been referred to in page 6. The result of the comparison then made between the waters of the tank and wells may now be given.

The water from the Dhobies' wells is almost identical with the tank water after filtration. It differs only by having a little less calcium carbonate and *organic* matter, and a little more silica and magnesia. The fact of its containing less organic matter renders it preferable for drinking purposes. The waters of the Ulsoor tank (filtered) and of the Dhobies' wells were compared with the standards laid down by Dr. Parkes, 1st, for pure and wholesome; 2nd, for usable drinking water. It was found that the tank water after filtration was equal to the second standard in every respect, and to the highest standard in all but three points. When further subjected to domestic filtration, the water from the Dhobies' wells comes up to the highest standard, and the Ulsoor tank water fails only in one point, viz., the larger amount of oxygen consuming organic matter, a defect common to all tank waters. Both waters exceed the highest standard on several important points, so that the sources of supply are exceptionally good.

In G. O. 528 of 26th February, 1872, the opinion of the Sanitary Commissioner upon the data deduced from the analysis is that, although under ordinary circumstances the water of the Ulsoor tank when filtered is perfectly pure and wholesome, and may be safely issued for the use of the troops, that the Dhobies' well water, owing to its freedom from all organic matter, is the safest and best.

Accordingly Government sanctioned the completion of both schemes, in order that they might mutually assist each other, the water from either source being transmitted by the same lines of piping to the same reservoirs.

The final revised scheme.—In anticipation of the same line of piping being available for either source, estimates for completing the two schemes had been submitted in November 1871 as ordered in the G. O. of June 1871.

To complete the Ulsoor project, all that was required was to continue the main to the east gate of the Infantry barracks to the cistern in the

Commissariat square, and carrying out the minor distribution which would practically complete the original scheme submitted in May 1869.

A further modification on this scheme was made by the provision of iron cisterns in the upper stories of the male and female hospital at the Agram barracks, so as to furnish the hospitals with a distinct house service.

It was at first intended that the iron cisterns in these hospitals were to be filled by a moveable steam engine at the hospitals. This, however, was found not to be required, as a sufficient command was obtained by the stand pipe on the rock. The cisterns were supported on cast-iron pillars resting directly on the ground, the weight being in no way carried by the walls of the building. The cisterns in the male hospital are each $22' \times 14' \times 2\frac{1}{2}'$, those in the female hospital $10' \times 10' \times 2\frac{1}{2}'$.

To complete the Dhobies' wells scheme in addition to the above works, 18 more wells had to be sunk, and a main laid on from the engine house to the sweet water basin at the rock. The Dhobies' wells scheme was the costlier by Rs. 22,400.

No provision was made for repairing the ruptured filter at the rock, and the useless half cistern at the Agram barracks.

The total amount required to complete the two projects was Rs. 3,01,698.

In the project provision was made for 15 gallons per head per day, or 86,000 gallons, but the Executive Engineer expressed his opinion, from the average consumption observed that, 10 gallons per head, and 8 gallons per horse per day, was probably enough.

In April 1872 the Government of India sanctioned the above estimates, remarking at the same time that either project singly would have sufficed for the supply of the Cantonment, but both projects being so far advanced, both must be completed.

As a spare filter was evidently required, the repair of the ruptured filter was also strongly urged by the Government of India.

Progress of the combined scheme.—As soon as sanction was obtained the extra wells were commenced. The wells were 20 feet deep, with a lower diameter of $9\frac{1}{2}$ feet, and upper of 10 feet each, for a height of 10 feet, lined with a loose stone backing of small stone, the mouths being closed by a granite slab square of 15 feet, with an opening of 3 feet left with a stone cover supported on two granite stones $15' \times 1' \times 1\frac{1}{2}'$.

The wells were connected with each other, and with the old wells by

horizontal driftways formed of stone. The floors were 4 inches above the bottoms of the wells, the side stones $2\frac{1}{2}$ feet high and $1\frac{1}{2}$ feet thick, floors of slab stones $4' \times 1' \times \frac{1}{2}'$, and covered by slab stones $4' \times 1' \times \frac{1}{2}'$ (see *Plate I.*)

In carrying out the work, the excavation for the wells was carried down to the full depth before the lining was commenced.

In addition to the extra 18 wells sanctioned, it was at one time proposed to sink 5 additional wells, and these were actually begun. They were, however, objected to by the Local authorities on the grounds that they endangered the safety of the bund, as they were sunk close to the rear slope. They were ultimately abandoned and filled in.

In 1874-75 the works connected with Ulsoor Water Work Project were completed.

Action taken with regard to the filter at the rock.—In September 1872 an estimate amounting to Rs. 8,490 was prepared for repairing the filter, which provided for picking up the flooring all round inside the walls for a width of 10 feet, excavating for a depth of $7\frac{1}{2}$ feet, filling in with a concrete lining backed by puddled clay, and replacing the flooring carefully by two courses of brick in cement. Before this was carried out, the condition of the cistern became worse, and it was decided to take up the whole of the flooring, and relay it with brick in cement 9 inches over concrete, 9 inches above a well rammed layer, 18 inches deep of laterite gravel. An estimate for such repairs was accordingly submitted, and repairs on this plan executed in May 1873.

Previous to the work being sanctioned, excavation had been carried inside and along the walls for the concrete lining, which was, however, not put in, puddled clay being used to fill in the excavation.

The new floor was laid as above detailed, and in addition an inside lining wall of brick in mud was constructed along the walls and plastered with cement, and the filtering material placed on the floor.

The filter was then filled, but it was found to leak as badly as ever. The wall near the road yielded, and was thrown slightly outwards, more so at the corner abutting on the road and farthest from the tank. Here too the side wall was ruptured, showing that there had been subsidence at this corner, which had torn the masonry away from the other portion. There are no working plans in existence showing the dimensions of the walls as actually constructed.

The excavations behind the walls revealed the fact that the lower courses of the masonry in the foundations were set in mud not mortar.

It was considered that leakage was due not to subsidence of the floor but to failure in the lower wall, and it was decided to be necessary to rebuild the walls in a thoroughly sound manner. Before proceeding to estimate for the entire re-construction of the walls, a very thorough examination of the site was made, the nature of which will be understood by a reference to plan of filter, *Plate IV*. Excavations were carried down at A, B, C, D and E, and in the first two cases rock was met with at a depth of 3 feet 5 inches and 2 feet 8 inches respectively below the floor, but at C, D, E no rock was found at depths of $26\frac{1}{2}$, $28\frac{3}{4}$ and $26\frac{1}{2}$. A shaft was then sunk at E, and below floor level the wall was found to consist of $1\frac{3}{4}$ feet brick in chunam, $3\frac{3}{4}$ feet stone in chunam, and below this again $4\frac{1}{2}$ feet of rock in earth, altogether the wall was 10 feet high below floor level. At the bottom of this shaft an iron rod was forced down for a further depth of 15 feet, but no rock was met with.

A portion of the floor was next removed just inside the wall, and after excavating for a depth of $15\frac{1}{2}$ feet, an iron rod was forced down for a further depth of $5\frac{1}{2}$ feet without rock being reached. Thus along the whole length of the wall by the roadside, rock cannot be found at depths varying from $25\frac{1}{4}$ to $28\frac{3}{4}$ below the floor, and a section of the filter and road embankment show that the floor is 18.43 feet above the ground, and 26.67 feet above the excavation made for the embankment at the time of forming the road. See *Fig. 6*.

The following information was also obtained regarding the condition of the site previous to the construction of the filter.

The original bund of the tank passed between the present filter and the pure water basin to the rock. Some little time before the filters were built, the road round the rock was formed; its crest being about $18\frac{1}{2}$ feet above the ground, and previous to this the ground between the old bund and the new road embankment was a marsh full of reeds. Shortly after the road was formed, the space between the two banks was selected as a suitable site for the filter. A good deal of rock had to be blasted on the site of the upper filter, and this *débris*, together with rock obtained from the surface of the rock, was used to fill in the marsh on the site of the lower filter. When this made earth, rock, &c., was brought up to what was considered a sufficient level, boulders in clay were built on it as a

foundation for the wall, on this stone in chunam, and above this brick in chunam to the level of the floor.

This being the method of preparing the site and building the wall, it is not surprising that the work failed. It is also probable that the site being built upon so soon after the construction of the road embankment, settlement occurred in the latter, and affected the site with the result of the failure of the walls.

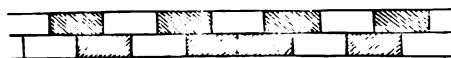
The masonry found in the walls was of fair quality, and the failure cannot be attributed to bad workmanship, but to a mistaken design.

Under the circumstances thus brought to light, it was evident that the work required to re-construct the wall of the filter upon a solid foundation would be very costly, in fact it was roughly estimated to fall not far short of Rs. 40,000. Accordingly in January 1876 Government decided that the repair of this portion of the filter must be abandoned, but as it was necessary that a second filter should be provided to allow of the one then existing to be cleaned or the filtering material changed, it was determined to build a second filter on a fresh site.

No ground was available near the original filter on the rock, but a site was selected near the engine house attached to the Dhobies' wells. The ground here being below the level of the water in the Ulsoor tank, a supply could be drawn thence by a syphon, and led on to the filter when required, and pumped thence by the Dhobies' wells engine to the pure water basin at the Ulsoor rock for distribution to the barracks.

Estimates for these works were accordingly framed and sanctioned in 1877-78.

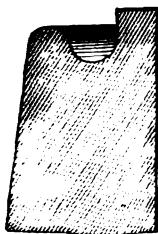
Working of the Ulsoor filter.—Previous to designing a new filter, the action of the one already working at the Ulsoor rock was tested. The surface area of the filter at the rock is 5,842 square feet. The depth and composition of the filtering material is as follows:—On the bottom of the filter are placed stone slabs 3 inches thick of different sizes varying from 2 to 4 square feet, placed so as to form conduits thus, the stone is then



brought up to a depth of 1 foot by small slab stones.

On this is a large stone jelly 1 foot in depth, capable of being passed through a $2\frac{1}{2}$ inch ring, above this 3 inches of small quarry sweepings covered by 4 inches of charcoal (vegetable), on which rests a layer of $2\frac{1}{2}$ feet of rather fine Bangalore sand.

The water from the tank is pumped into a trough running along the top of one wall for the whole width of the filter, which allows the water to pass quietly over a smooth curved edge into the filter as shown in sketch. Vertical iron pipes are erected to allow the air from below to escape, and prevent its disturbing the sand while it is being filled.



The following is the method of collecting the water and conveying it to the pure water basin after it has passed through the filtering material. The floor of the filter slopes gently to the corner whence it is to be discharged. The water falls through the filtering strata to the stone conduits placed on the floor, and from thence passes to an arched brick conduit, built along that side of the filter which contains the outlet to the pure water basin. The maximum head of water on the filtering material is 3 to 3½ feet. The quantity of water filtered was carefully gauged from 7 A.M. September 15th 1875, to 7 A.M. on 16th idem, when it was found that 48,000 gallons had been filtered in 24 hours. The filtration took place under most favourable circumstances, as the day before trial the sand was scraped and dug up to a depth of 18 inches, and moreover the filter having been in use for some time, the depth of the layer of sand had been reduced some 7 inches by repeated scrapings. During the trial the head of water varied from 3 feet 7 inches to 2 feet 3 inches. Thus under the most favourable circumstances the filter cannot purify more than $\frac{48\,000}{5,842} = 8.216$ gallons per square foot in 24 hours.

Directly the discharge into the pure water basin shows signs of imperfect filtration it is checked by a valve.

Additions to the Ulsoor Water Works.—In 1876-77 the old engine at the Dhobies' wells was removed, and replaced by a new compound horizontal engine of 10 horse-power, pumping on an average 13,400 gallons per hour = 223 gallons per minute.

In 1877-78 an estimate of Rs. 66,598 was sanctioned for additions to the Ulsoor water works, which provided for iron roofs to the cisterns and pure water basin, fixing the new engine and pumps at the Dhobies' filter, and providing the additional filter. These works, together with a pure water basin, have been completed, and nothing further remains to be done to the work except to roof two of the cisterns.

The filter and pure water basin at the Dhobies' wells.—When the plans for the new filter with the arrangements for distributing the water in connection with it were first drawn up, it was intended that the filtered water from the filter should be conducted to the pumping well direct, and thence pumped to the pure water basin at the rock.

This plan was objected to by Major A. D. C. Scott, R.E., the Deputy Chief Engineer for Irrigation, on the grounds that as the pump well is connected with the system of wells, if the filtered water were allowed to pass into it, it would diffuse itself through the system of wells without materially raising the level of the water in the pump well in which the suction pipe works.

He directed that a small pure water tank of about one-quarter the capacity of the filter should be constructed near it, to which the filtered water should pass, and that when using Ulsoor tank filtered water the engine should pump direct from this pure water tank and not from the pump well. The yield of the filter being 40,000 gallons, or one day's supply, that of the pure water tank was to be 10,000 gallons.

The Engineer in charge of the works believed that this diffusion would not take place to so large an extent, as the laterite strata in which the wells are sunk is surrounded by a bed of stiff clay, and the pumps would draw from the whole bed of water.

The pure water tank being of so small a capacity, would be emptied by the pumps in about half an hour, and the engine would then have to stop working or draw from the wells until the pure water tank filled again. The Engineer contends that this spasmodic mode of working the engine would be costly and injurious to the machinery. Colonel Moberly R.E., lately in charge of the Division, proposed to overcome the difficulty by having a double branch from the suction pipe in the pumping well provided with valves, so that upon the tank becoming empty, the engine could be turned on to the supply from the Dhobies' wells without stopping until the tank had filled again.

Revised plans and estimates for the filter and a pure water tank were submitted, which can be understood by a reference to the *Plates*. The arrangement and depth of filtering strata were similar to that adopted in the filter at the rock, but the construction of the flooring was very different, the floor consisting of $2\frac{1}{2}$ feet of puddled clay laid in layers 6 inches thick, next a layer of stone metal 8 inches thick set in clay well

rammed, and above this 4 inches of concrete laid in furrows and ridges, the furrows leading along the short width of the filter. In the furrows stone drains were laid, packed with loose stone, over which was laid the filtering strata, *see Plate III.*

The water flows into the filter from a trough along the top of one wall, as in the one at the Ulsoor rock, but instead of being lead as there into an arched chamber after filtration, the stone drains conduct it to a perforated iron pipe laid along the foot of the wall, which leads the water to the outlet pipe into the pure water basin.

The filter has not been carried out exactly according to the plan. The concrete sloping walls were found to bulge, and they were covered with a casing of brick in chunam in steps.

On testing the filter it was found to leak very considerably, and the irregularities of the faces of the inner walls were filled in with concrete, and the whole plastered with surki and Portland cement. I regret to say that the filter leaks still, though to not nearly the extent previously. Leakage here is not of great consequence, as the filter is filled from the tank by gravitation, and what water does escape probably finds its way to the wells close by.

The scheme as complete.—The works are now complete in all their details, and it remains to enquire into their working, and their capabilities as to their supply compared with the requirements of the garrison.

The existing system of water supply for the European troops at Bangalore may be briefly described thus—

I. *Source of supply.*—The Ulsoor tank and Dhobies' wells situated about one mile from the most distant barrack to be supplied.

II. *Head works.*—Engine house and 12 horse-power engine and pumps, filter, pure water basin and stand pipe, quarters for the Engineer in charge at the Ulsoor rock; engine house, 10 horse-power engine and pumps, 32 wells, small pure water basin and filter at the Dhobies' wells.

III. *Distributing arrangements.*—12,208 feet of cast-iron main pipes, of diameter ranging from 10 inches to 4 inches. Single masonry cisterns at the Cavalry and European barracks.

A double masonry cistern at the Royal Horse Artillery barracks.

Four wrought-iron cisterns in the hospitals at the Cavalry barracks.

85,461 feet of cast-iron distributing pipes, ranging from 7 inches to $\frac{1}{2}$ inch diameter.

49 Stand cocks.

IV. *Population to be supplied—*

	Men.	Women.	Children.	Native followers.	Horses.
1 Battery Royal Horse Artillery,...	157	24	27	317	178
1 Regiment Cavalry,	455	56	142	567	436
2 Batteries Royal Artillery, ...	314	43	74	418	220
1 Regiment Infantry,	886	104	178	...	...
Totals, ...	2,460			1,302	834

V. *Demand—*

14 Gallons per day per European.

1 Gallon " Native.

12 Gallons " Horse.

Therefore—

Royal Horse Artillery require 5,493 gallons per day.

Royal Artillery " 9,078 "

Cavalry " 14,941 "

Infantry, " 16,852 "

Total, ... 45,864 = 46,000 gallons, say.

The supply is drawn from the Dhobies' wells by preference, is pumped by the engine there to the pure water basin at the rock, whence the engine at the rock pumps it to the cisterns at the barracks.

If the supply in the Dhobies' wells fails, which it generally does during the hot months when the tank is low, the supply is drawn from the tank and pumped into the filter at the rock, whence it gravitates into the pure water basin, to be pumped up by the engine to the stand pipe, and thence to the cisterns at the barracks.

If the filter at the rock is out of order or requires cleaning at a time when the full supply cannot be drawn from the Dhobies' wells, the tank water can be allowed to flow by gravitation into the filter at the Dhobies' wells, and on to the small pure water tank there, whence the Dhobies' wells engine pumps it up to the pure water basin at the rock, to be sent on as before by the engine there.

The actual capacities of the several filters and reservoirs are as follows:—

Filters.—

	Gallons.
The filter at the rock can purify per day	87,971
That at the Dhobies' wells	32,500
The pure water basin contains	149,425
Royal Horse Artillery cistern contains	179,025
Cavalry barrack cistern contains	280,087
Infantry „ „ in Bakery square	112,500

Comparing these figures with the statement of probable demand given above, it will be seen that the capabilities of the works are as follows:—

The filters can purify	1½ days' supply for the garrison.
The pure water basin holds	3½ „ „
The R. H. Artillery cistern holds	32 6 days' supply for the R. H. Artillery.
The Cavalry barrack cistern holds... ..	12·1 days' supply for one Regiment Cavalry and 2 Batteries Royal Artillery.
The cistern in the Bakery square,... ..	6·8 days' supply for one Regt. Infantry.

It may be noticed that the cistern in the Bakery square has to meet demands not only for supply to the Infantry, but also to the Bakery and Commissariat buildings, the requirements of which cannot be correctly ascertained. It would not, however, be very great.

The following is a description of the engines.

The one at the rock cost £2,000 in England, and is a Watt's double acting beam condensing low pressure engine of 12 horse-power nominal, with a piston area of 254·5 square inches, and length of stroke of 22 inches, driving three force pumps with cylinders 1 foot in diameter, and plungers of 2 feet stroke, capable of raising 410 gallons per minute. The average rate of pumping is 300 gallons per minute.

The engine at the Dhobies' wells cost £1,138 in England, and is a direct, double-acting, compound horizontal condensing engine of 10 horse-power nominal, working under high and low pressure; area of high pressure piston 53·5 square inches, and of low pressure piston 188·7 square inches, length of stroke 12 inches, driving three force pumps with cylinders of 10 inches diameter, and length of stroke of plungers 18 inches, capable of raising 288 gallons per minute, the average rate being 223 gallons per minute. Both engines work expansively. The boilers are cylindrical, thickness of plate $\frac{7}{8}$ -inch, that at the Ulsoor rock being 12 feet long, 4 feet 8 inches diameter, with 22½ inches fire grate surface, and that at the Dhobies' wells being 12' × 5' 1" diameter, with 14½ inches of fire grate surface.

Both engines burn wood.

The following are data deduced from observation of the working of the two engines.

On 15th September the Ulsoor rock engine pumped up 128,565 gallons from the pure water basin to the Cavalry barrack cistern in 5 hours 13 minutes, a rate of 410.75 gallons per minute, and burnt 2,355 lbs. of wood. On the same day, the same quantity was pumped up by the Dhobies' wells engine to the pure water basin in 9 hours, a rate of 238.0 gallons per minute, with an expenditure of 3,874 lbs. of fuel.

The lifts are as follows :—

From wells to pure water basin, 86.25 feet.

From pure water basin to top of stand pipe, 78.00 feet.

The nominal horse-power to accomplish this would have been in the rock engine $\frac{410.75 \times 78 \times 10}{33,000} = 9.10$, or adding 50 per cent. = 13.6 horse-power, and in the wells engine $\frac{238.08 \times 86.25 \times 10}{33,000} = 2.7$, or adding 50 per cent., 4.05 horse-power.

In the rock engine the indicated pressure was 20 lbs. per square inch, and the number of strokes per minute 45, so that the indicated horse-power was $\frac{2 A, P, R, S}{33,000}$, where A = area of piston, P = pressure per square inch, R = number of strokes per minute, and S = length of stroke in feet = $\frac{2 \times 254.5 \times 45 \times 22}{33,000 \times 12} = 25.5$ horse-power, or more than double the nominal horse-power of the engine.

In the Dhobies' wells engine the steam was working at 50 lbs. pressure, and the number of strokes per minute was 40, so that the actual horse-power was $\frac{2 \times 53.5 \times 40 \times 50 \times 1}{33,000} = 6.5$ horse-power.

The expenditure of fuel in the rock engine was 230.5 lbs. per hour, producing an indicated horse-power of 25.5, while the indicated horse-power in the Dhobies' well engine being 6.5, the consumption of coal was 430 lbs. per hour. From this it would seem that the engine at the Dhobies' wells is very costly as regards fuel, but the above calculations are rough only, it is very probable that I have under-estimated the actual horse-power of the wells engine. The main from the Dhobies' wells to the pure water basin is small, only 5 inches diameter, and considerable additional power is probably required to drive the water through this

small piping, and, moreover, there are no indicator diagrams kept, so that it is impossible to know exactly how the steam is working in the cylinders.

Supposing it were ever wished to pump the water from the wells straight up to the barracks, I am inclined to think that the Dhobies' wells engine would be sufficiently powerful to accomplish it, but it would be necessary to replace the small 5 inch main by a 10 inch main connected with the main from the stand pipe at the Ulsoor rock.

The top of the stand pipe on the rock is 107 feet above the low water mark of the wells, and the engine would have to force the water through the pipes with a pressure equivalent to this lift.

Supposing the engine to pump at a slower rate of 200 gallons per minute, in which case it would raise 96,000 gallons, or two days' supply in 8 hours, the nominal horse-power required would be $\frac{200 \times 10 \cdot 7 \times 10}{88,000} = 6\frac{1}{2}$, or adding 50 per cent. = 9.75, or 10 horse-power the present nominal horse-power of the engine.

Pumping with a single engine would effect a saving in fuel.

In place of a stand pipe at the Dhobies' wells the main from the engine is provided with a spring valve adjusted to support a pressure up to 50 lbs. on the square inch, equivalent to a head of water of 115.47 feet.

From the returns of the working of the system for the last official year, the following is obtained :—

Quantity of water pumped up daily (average),	...	48,460	gallons.
" " filtered,	...	11,665	"
" fuel expended daily,	...	8,887	lbs.
<hr/>			
Monthly cost of fuel,	...	377	0 0
" " establishment,	...	506	0 0
" " repairs,	...	12	4 0
<hr/>			
Total,	...	895	4 0
<hr/>			

Say Rs. 900.

In last official year the total quantity of water pumped up from the wells was 14,419,800 gallons, equal to $\frac{14,419,800}{32} = 450,620$ gallons per well. The total quantity pumped up to the barracks was 15,863,858 gallons, so that only 1,444,058 gallons had to be drawn from the Ulsoor tank.

It may be noted that had the 5 wells commenced and abandoned in 1876 been completed, an additional yield of $450,620 \times 5 = 2,253,100$ gallons might have been expected, in which case the entire supply could have been obtained from the Dhobies' wells. It must, however, be remembered that during 1878-79 the garrison was under its full strength.

Cost of the work.—It is not possible to give a correct statement of the cost of the project in detail. As will have been seen from what has been already stated, a good deal of work has been done that was ultimately abandoned, and no account has been kept of the various works under separate heads. In addition to this expenditure, an account of conservancy and repairs has been mixed up with the accounts of the work, together with cost of stores received from England, and after all not required, while a good deal of the work in connection with the Dhobies' wells scheme was carried out before the estimates were prepared.

The amount originally sanctioned in 1862-63 was Rs. 72,000. This was several times increased, as has been already noticed, and in 1871-72 the cost of the Dhobies' wells scheme, which had sprung into existence in the interval, was amalgamated with the Ulsoor rock scheme, and the whole amount sanctioned for the completion of the two schemes was Rs. 3,01,698. Of this Rs. 2,77,347-2-1 has been spent up to 1875. In 1877-78 an estimate for Rs. 66,598 was sanctioned for additions to the water works, which was made up as follows :—

	Ra.
Iron roof to pure water basin,	6,700
" " Agram cistern,	16,520
" " Royal Horse Artillery cistern,	10,450
" " Bakery cistern,	4,230
Additional filter with piping,	12,600
Fixing new engine and pump at Dhobies' wells,	16,098
Total,	<u>66,598</u>

Of this Rs. 23,245-6-1 has been spent up to date.

To recapitulate—

	Ra.
Total amount sanctioned,	3,68,296
" " spent,	<u>3,00,592</u>
Balance unspent,	67,704
Remaining to complete—	Ra.
Iron roof to Agram cistern,	16,520
" " Royal Horse Artillery cistern,	10,450
Probable balance on final completion,	<u>40,734</u>

From what records I can find, I estimate the cost of some portions of the work as follows:—

	Ra.
1. Cisterns at Cavalry barracks,	9,500
2. " Royal Horse Artillery,	3,800
3. " Royal Artillery (abandoned),	2,720
4. " Bakery square,	5,820
5. Two iron cisterns (small),	2,500
6. Two " (large),	10,740
7. Pure water basin,	6,351
8. New filter,	7,755
9. Sinking and connecting the wells,	13,300
10. Purchase of ground,	2,342
11. Engine house at wells,	8,000
12. Chimney 80 feet,	2,560
13. Engine driver's quarters,	2,480
14. Stand pipe,	345
15. Piping,	97,537
16. (49) Stand cocks, each,	35
17. Iron roof to pure water basin,	6,351
18. " cistern, Bakery square,	4,006
19. Repairs at various times,	10,872

Beyond these items I can give no other detail of expenditure, the above are given here as they might form a rough guide hereafter in approximating the cost of somewhat similar schemes to be undertaken elsewhere.

General Remarks.—It will be seen that the scheme as carried out falls short of the objects proposed to be secured in Lieut. Tulloch's original project in more than one particular.

1. The supply of pure water that the two filters can yield in 24 hours is not more than 70,471 gallons, or not two days' supply, while as originally intended, the main filter was to have supplied three or four times an estimated daily draft of 60,000 gallons.

2. With the exception of the Royal Horse Artillery cistern, none of the other reservoirs are capable of storing a month's supply, and supposing any serious accident to happen to the machinery or pure water basin, the supply for the Infantry would probably be exhausted before the system could be brought into working order again.

3. Settling beds have not been provided; to this fact, I think the slow filtration may be attributed. The tank water contains a very large quantity of suspended matter. The appearance of the filter when empty shows

that the surface of the sand stratum is thickly caked with clay, a circumstance that must after a time tend to retard the descent of the water through the filtering media, besides necessitating frequent scraping and partial removal of the sand.

It will be observed that there is only one pure water basin capable of holding little more than three days' supply, and that the uninterrupted supply both from the tank and from the Dhobies' wells is entirely dependant upon the integrity of this reservoir. Great stress was laid upon the importance of having a second filter in case one should require repair, and it seems to me that the necessity of a reserve pure water basin is equally important. In fact I am of opinion that this is of greater importance, for whereas a filter is a link in the Ulsoor rock scheme alone, which in no way affects the system of supply from the Dhobies' wells, the pure water basin forms a most important link in the two schemes, any failure in which would paralyze the action of either system unless arrangements are made to pump from the wells direct. A site for a second pure water basin could be found on the north of the rock near the boat house.

I would also notice what appears to me a serious point in the character of the water supply. Regarded as a system of supply to a town, it is doubtless ample for all its present requirements, and with the enormous capacity of the main source of supply, the Ulsoor tank could be extended to meet much larger demands. But as a Military source of supply it is open to the serious defect of insecurity. The water works, the fountain head of the supply, are situated at a distance from the barracks, are in no way defended, and in the event of an outbreak, a small expenditure of time and gunpowder would suffice to inflict such damage to the machinery as would stop the water supply entirely for very many months, while with a little skill the whole scheme might be so effectually damaged as to require re-construction almost from the commencement.

It seems to me that to provide for such a contingency, improbable it is to be hoped, but by no means impossible, the system of tanks distributed among the barracks for catching and storing the rain water from the roofs should be carried out, and which would render the barracks independent for drinking water of supply from the water works should any serious disaster happen to them.

The cisterns were constructed without the cross walls and archways to

induce a free circulation of water. This is to be regretted, as the construction of these cross walls would have added very little to the cost of the cisterns, and had they existed, it would have been possible by their means as intermediate supports to roof the cisterns at a comparatively moderate cost. The corrugated iron roofs now put up over the pure water basin and cistern in the Bakery square are supported on wrought-iron trusses carried on heavy cast-iron shoes which have to be bolted into the walls, and are very costly.

The failure of the filter and cisterns point I think to the advisability of using a flooring other than stone flags on concrete over a basement filled in with made earth. The floor of a cistern is always its weak point. When constructed of flags, unless the stones are very carefully and truly dressed, there is always a difficulty in cementing them up properly at the joints, and the space X may be left clear inducing leakage, which



once commencing may lead to grave results. Where the earth beneath the flooring is made earth, unless it is well puddled and plenty of time is given to it to set, shrinkage must ensue more or less, which by reason of the super imposed weight of water is sure to be followed by subsidence and cracking of the floor. This appears to have been the cause of failure in the cisterns. A stronger and more reliable flooring would result by constructing it of arches turned on cross walls in the basement, and brought to a level by concrete and asphalte or cement. Constructed in this way, the flooring would not be affected by any subsidence of the earth beneath, and if a water-tight floor is obtained thus, the additional cost would fall far short of the amount required to repair the filter, supposing the floor to have been constructed of flags on concrete and found to leak. The only instances where the cisterns in connection with the Ulsoor water works did not leak, are the pure water basin, the cistern at the Commissariat square, and the upper filter at the rock. In each of these cases the floor rested on firm soil or rock and not on made earth.

From the returns of the consumption of water by the troops during the last official year, it will be seen that the average daily consumption of the troops when the garrison was reduced by the absence of one Regiment of Infantry on service has been very nearly equal to the estimated demand for the garrison when at its full strength. Judging by the

consumption of the past year, with the full compliment of troops in Bangalore, the amount of water used would be not far short of 50,000 gallons daily, or 16.38 gallons per head per European.

This is in excess of the estimated demand of 14 gallons per head, which, to judge by the provision made in water supply systems elsewhere, is ample, and much in excess of what was assumed as the proper demand in the project first submitted in 1862. It also exceeds what was found to be sufficient in 1871, as noted in page 21. This point deserves attention; greater economy in the consumption of the water would lead to economy in fuel and pumping.

No opportunity has yet occurred for testing the arrangements for drawing water from the filter and pure water basin at the Dhobies' wells. Water has stood high in the wells all this year, and until it falls the connections for pumping from the pure water well direct cannot be made, as the pipes where the joints have to be made are 6 feet under water. As soon as possible the connection will be made, and the working of the plan reported on.

F. J. R.

REPORT ON THE ULSOOR WATER WORKS.

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Number of wells 16, each 10 feet in diameter, together with one pump well (connected with the foregoing) of 6 feet in diameter. One foot of water in the wells is equivalent to 8,080 gallons. Storage capacity of all the wells is equivalent to 144,550 gallons. One revolution of pump shaft is equivalent to 1.79 gallons. Zero on gauge being sill of Ulsoor waste weir.

Month and date	Number of hours engine at work.	Number of revolutions per minute	Total number of revolutions per day	Reading of gauge in wells		Depth of water		Total number of gallons of water pumped		Depth of water re-gained by filtration into the wells				No. of gallons required by filtration into the wells		Rainfall	Depth of water below sill of waste well (Ulloor tank) in feet	Remarks		
				morning	evening	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches				During pumping by day	Night
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
1871.																				
20th May,	10	40-63	24,581	18	6½	17	3	8	2	1½	1	..	16,989	8,700	..	..	..	The engine used was the old one since removed. Part of a day's work.		
21st "	7½	61-5	27,700	16	2	19	10	8	5	2	2	19,361	16,060	..	..	8-8				
22nd "	7	65-95	27,700	17	10	20	11	8	1	2	2	23,376	16,060	..	..	..				
23rd "	7	65-95	27,700	18	11	21	7	8	1	1	1	27,391	16,390	..	..	..				
24th "	7½	65-95	28,550	19	8	22	0	4	9	3	11	31,500	12,715	..	0-390	..				
25th "	7½	65-95	28,550	20	5	23	7	2	9	4	1	32,809	12,715	..	0-425	..				
26th "	5½	56-6	11,870	21	0	23	8	1	7	3	5	19,431	16,779	..	0-115	..				
27th "	..	..	..	20	9½	20	0	..	..	..	..	5,350	6,357	0-150	..	..				
28th "	..	..	..	19	4	19	0	..	..	7½	4	..	5,020	2,677	..	..	..			
29th "	..	..	..	18	4½	17	10½	..	..	5½	5½	..	3,850	3,850	0-005	..	..			
30th "	..	..	..	17	5	16	10½	..	..	..	7½	..	..	5,020	0-160	4-0	..			

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BANGALORE :
16th June, 1871. }

BANGALORE :
30th September, 1873. }

(True Copy)

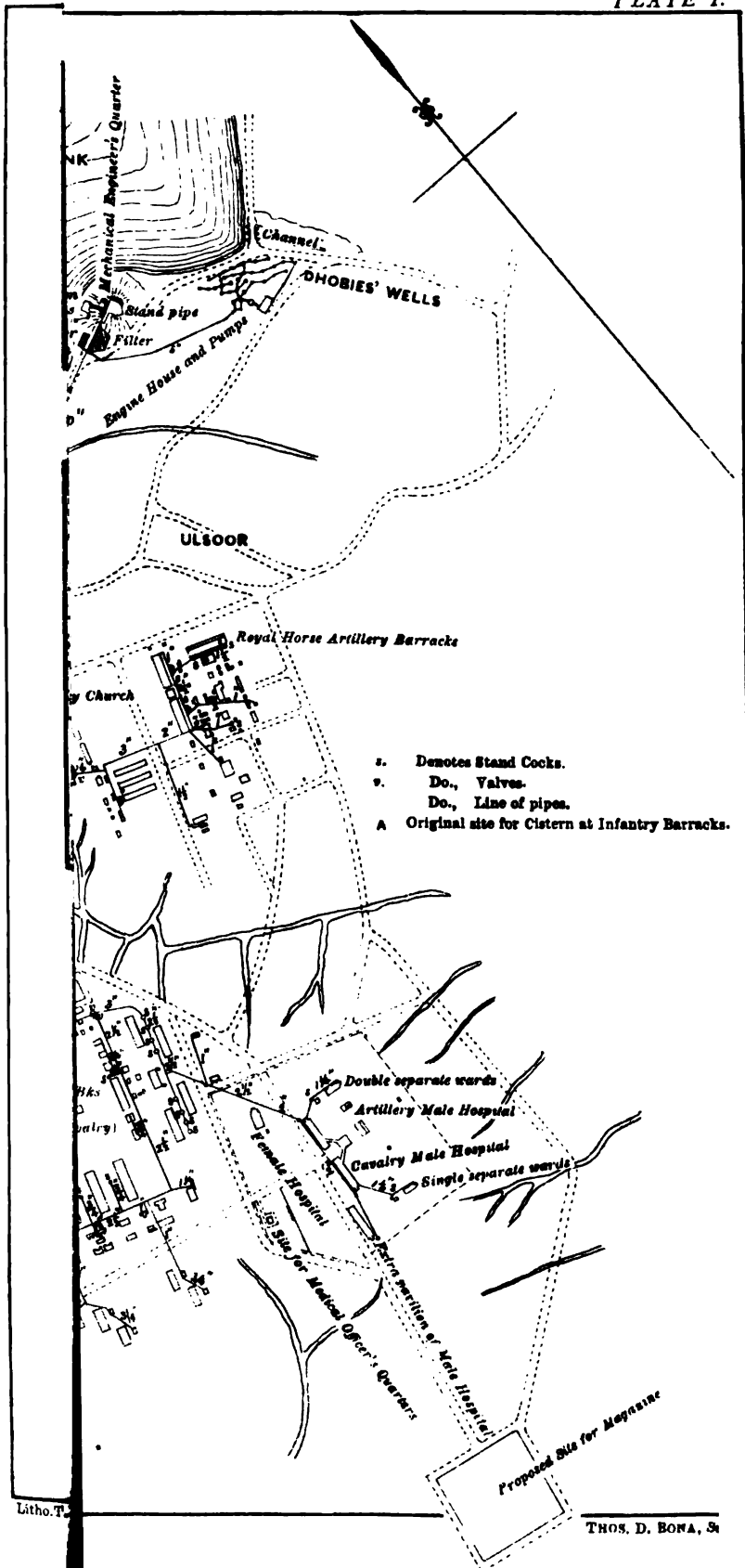
(Signed) H. W. WOOD, CAPTAIN, R.E.,
Esac. Engineer, Bangalore.

(Signed) F. J. BOMILLY, LIEUT., R.E.,
Esac. Engineer.

1. 1. 1.

2. 2. 2.

3. 3. 3.



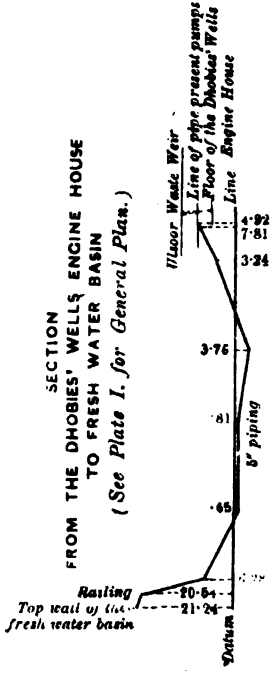
REPORT ON THE ULSOOR WATER WORKS.

Horizontal Scale, 8888 feet to an inch.

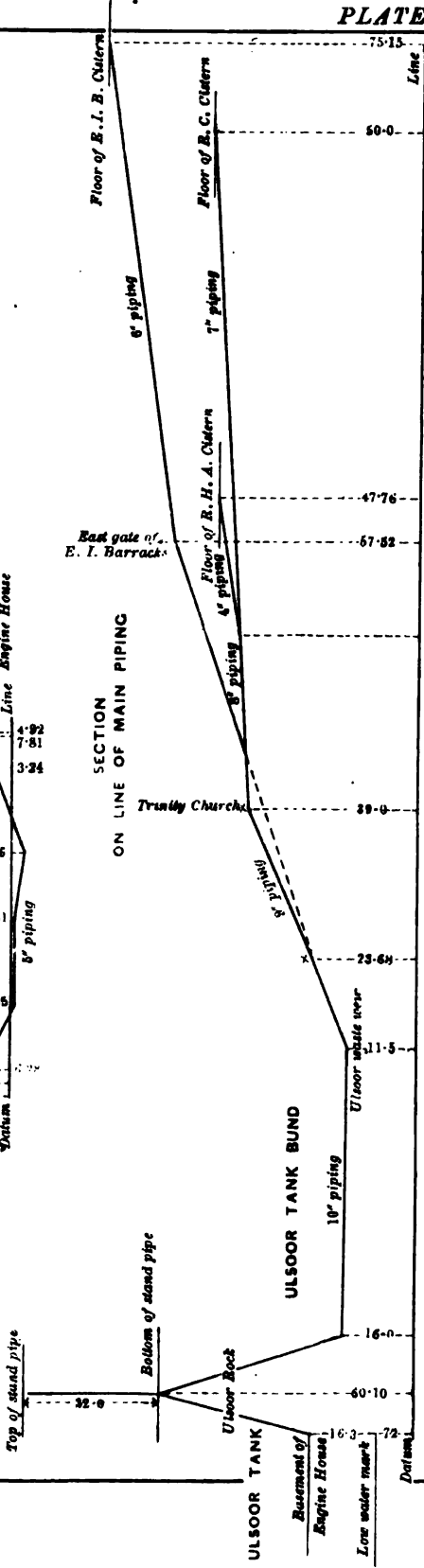


Vertical Scale, 444 feet to an inch.

SECTION
FROM THE DHOBIES' WELLS ENGINE HOUSE
TO FRESH WATER BASIN
(See Plate I. for General Plan.)



SECTION OF MAIN PIPING ON LINE OF MAIN PIPING



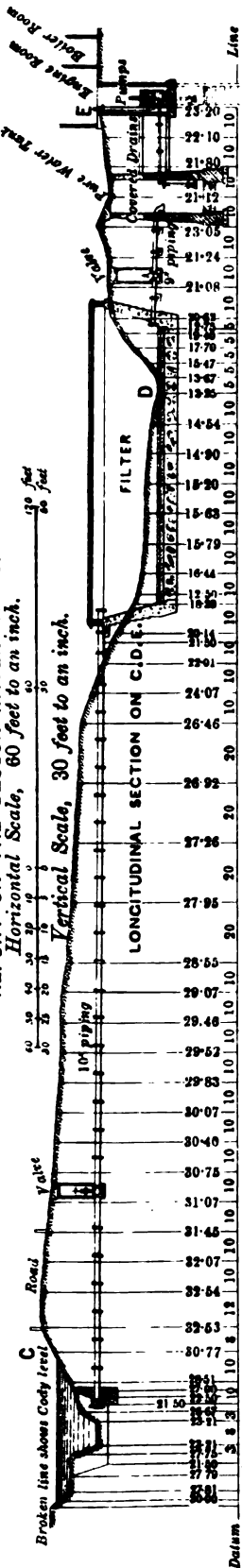
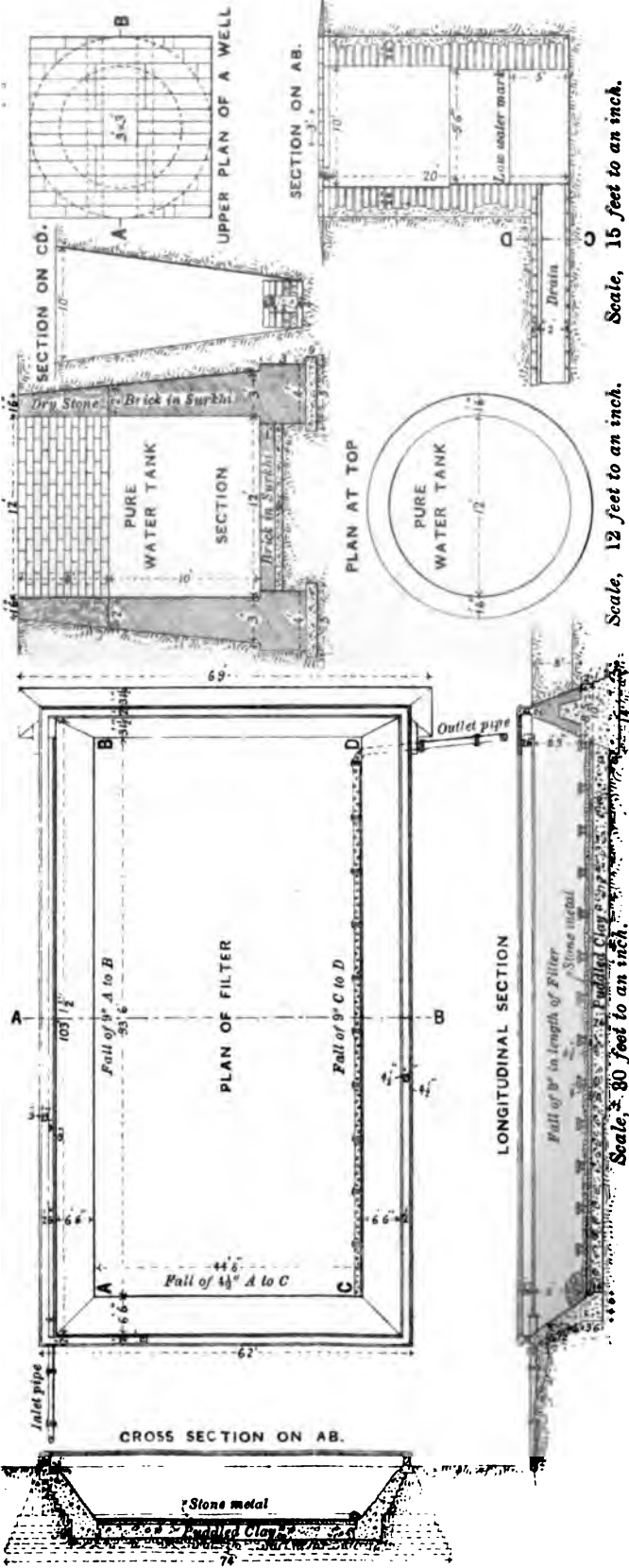
Libo. T. C. Press, Bombay.

THOS. D. BONA, Supdt.

HEPUHI ON THE ULSOUR WATER WUHK.

Horizontal Scale, 80 feet to an inch.

Vertical Scale, 30 feet to an inch.



REPORT ON THE ULSOOR WATER WORKS.

PLAN OF FILTER ON THE ULSOOR ROCK.

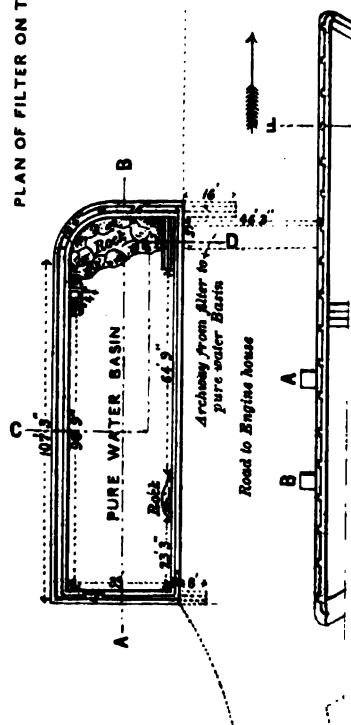


FIG. 1.

SECTION OF PURE WATER BASIN

SECTION ON CD.

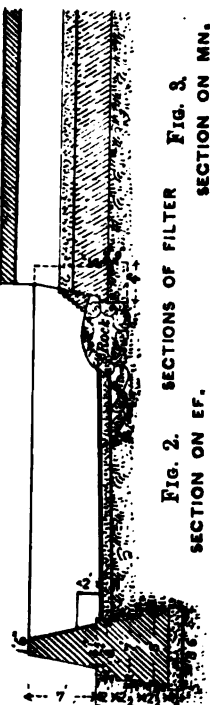


FIG. 2. SECTIONS OF FILTER

SECTION ON MN.

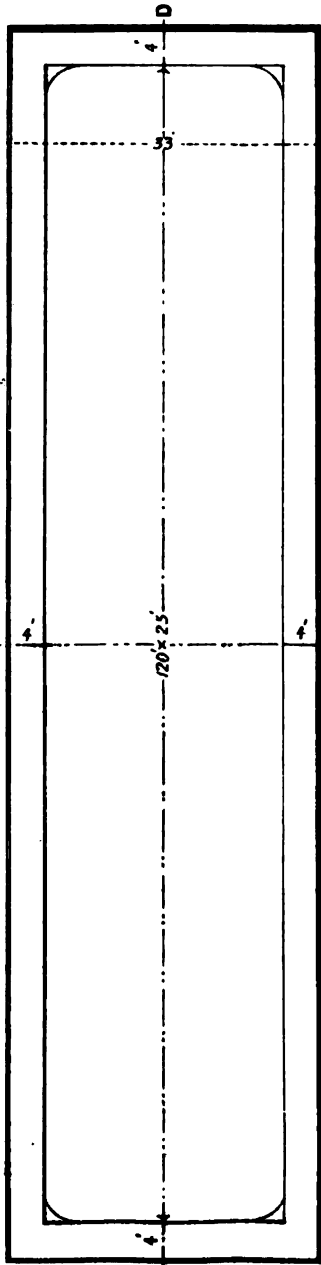


REPORT ON THE ULSOOR WATER WORKS.

Scale, 20 feet to an inch.



PLAN OF CISTERN FOR INFANTRY BARRACKS.

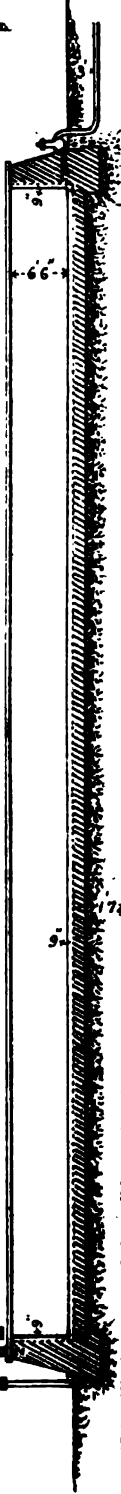


SIDE ELEVATION



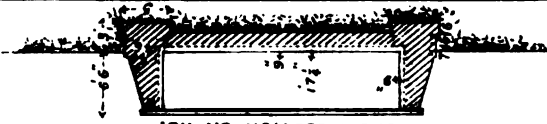
Flooring—3 courses brick-on-edge in Portland cement over brick in chiselm.

LONGITUDINAL SECTION ON CD.



N.B.—The lower part of the wall has an interior hearting of stone concrete.

CROSS SECTION ON AB.

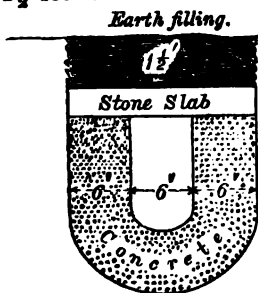


No. CCCXXXIV.

ALMORA WATER SUPPLY,

By T. W. ASHHURST, Esq., *Exec. Engineer, Kumaon Division.*

THE water is collected from springs and ravines by a lateral open channel (which can be closed at will) generally cut in rock and lined with concrete. This channel is placed at about 2 feet below ground surface, and is covered tightly with stone slabs, over which there is filled about $1\frac{1}{2}$ feet of earth. It is a continuous channel constructed throughout of



concrete (see sketch), and is large enough to contain double the minimum supply. The concrete is composed of 7 parts quartzite, broken to 1 inch cubes, to 2 parts sharp river sand and 1 part lime, plastered over with a plaster composed of 1 Portland cement to 3 lime and 4 sand.

During the dry weather this channel is kept free from silt and debris by silt trap and filter beds, and all available water is turned in from all springs, but in heavy floods during the rains, when the springs flow copiously, only one spring (that at Dhobies' ghat) is required for the town supply, and all others are shut off. The most distant stream is about $3\frac{1}{4}$ miles from the town.

The minimum supply in the dry season was taken at 2 cubic feet per minute, which was well under the minimum measurements taken over several years.

The population of Almora is about 8,000, so that a supply of 2 gallons per day for each person was given.

The average velocity of flow is 8 feet per second.

The filter beds have an area of $40' \times 10'$, and are capable of filtering 81,150 gallons in 24 hours. The filtering medium consists of $2\frac{1}{2}$ feet fine sand, 6 inches coarse sand, 6 inches fine gravel, and $2\frac{1}{2}$ feet gravel, $\frac{1}{2}$ -inch to $\frac{3}{4}$ -inch diameter.

The storage reservoir is $100' \times 10' \times 10'$, containing sufficient water for seven days' supply.

There is an ornamental fountain in front of the School house, supplied by a 8-inch cast-iron pipe, the overflow from which is collected in a waste tank at a lower level, and the distribution is made by water posts at convenient intervals and flow nozzles at the extremity in the centre of the town.

The total cost was about Rs. 21,000.

ALMORA, }
13th February, 1880. }

T. W. A.

No. CCCXXXV.

WATER SUPPLY, AHMEDABAD.

[*Vide* Plates I and II.]

By LIEUT. J. NEVILLE, R.E., *Exec. Engineer.*

It appears that in 1849 the existing building at the head works was built by Lieutenant Dickinson, R.E., the then Executive Engineer. Water was at that time raised by means of four Persian wheels. The total cost of the building with wheels, filtering beds, air shafts, &c., was Rs. 1,09,583, obtained from Municipal Funds. In about 1865 the Persian wheels being found inadequate, pumping engines were obtained from Messrs. Nicol and Co., Bombay. Fresh distribution pipes were laid; the funds being always supplied by the Municipality.

Up to this time the execution and maintenance of works had been in the hands of the Executive Engineer; but about 1878, after some correspondence, the works were transferred to the Municipality, and looked after by the Municipal Secretary. Schemes of improvements were, however, referred in some cases to the Executive Engineer.

Population and Distribution.—An idea of the present arrangements for distribution will be obtained from the small city plan (*vide* Plate I.) which accompanies this report. Water is only distributed over about one-third of the city, and in those quarters, owing to caste, only one-half of the population avail themselves of it. Taking everything into consideration, 25,000 people, out of a total of 111,680 within the city walls, may be said to benefit by the works. As the daily supply is 138,000 gallons, consumption may be said to be 5 gallons per head per diem.

Site.—The head works are situated to the south-west of the city at the edge of the river Sābarmati, which at this point flows under the walls. The site has been strongly objected to by the Sanitary Commissioner, on

the ground that this being the down-stream end of the river, all sewage and impurities discharged higher up are carried past the pumping station, thus polluting the supply at its source. In consequence of this opinion, a proposed extension of the works was abandoned. Alternative schemes of a point of supply higher up the river, and of water supply from the Khári river, have been suggested.

Pumping Engines.—The pumping station is a large two-storied building, the pumping engines (horizontal) of 5 horse-power and 6 horse-power respectively, being situated on the ground floor. The water is raised to a height of about 52 feet by iron pipes, at the lower extremities of which are flexible tubes terminated by perforated copper caps. The two engines lift together 133,000 gallons in 10 hours, viz., from 6 P.M. to 4 A.M., less impurity being likely to be in the river in these hours.

Filtering Arrangements.—The filtering arrangements in the upper story will be understood from *Fig. 1, Plate II.*

The water is first admitted into the settling tank, which is about 755 square feet area, and 5,574 cubic feet capacity, above lowest pipe of communication with filters A and B. As, however, 133,000 gallons, or 21,280 cubic feet are pumped up in 10 hours nearly, all this must pass through settling tank to filter, and thence to storage tank and main pipe; during the working of the pumps, the value of this settling tank is doubtful. The two filtering tanks A and B have a total area of about 352 square feet. The filtering material consists of 1 foot charcoal, 2½ feet coarse kunkur, and 6 inches finer kunkur. The process of filtration is still more rapid than that of settling, and can hardly be considered adequate.

Supply Arrangements.—The main from the pumping station consists of two earthenware pipes 8 inches in diameter. The cast-iron pipes used are of 2, 3 and 4 inches diameter. Air shafts, varying with the pressure from 30 feet in height, are constructed of brick and lime masonry, at intervals of 800 feet to 1,000 feet. Syphons called “Madians” of brick and lime used to be exclusively employed at points of junction of branch pipes as shown in *Fig. 2, Plate II.*

To stop a branch supply with the above arrangement, a man has to climb up and put a wooden plug in the hole A communicating with the branch pipe. This antiquated system is necessitated by the use of earthenware mains which cannot stand high pressure. With the cast-iron piping cast-iron junction pipes are used.

Water is drawn either from iron stand pipes or from covered tanks. The latter are something of the cross section shown in *Fig. 3, Plate II.*; and 26 hib-cocks are attached to the outer face, so that several can draw water at the same time. A man is kept in charge of each of these tanks, but it is difficult to make the people turn off the cocks after filling their vessels, and the waste is considerable. To some of these reservoirs open troughs for cattle are attached.

Water Rates.—Service pipes are laid for private supply, and the consumption is regulated by meters; the rate being 8 annas per 1,000 gallons. There are only 13 service pipes however, and the annual receipt is Rs. 225, which is credited to the general fund. There is no water rate other than that of the service pipes.

Cost of Maintenance.—The daily cost may be taken as follows :—

							Rs.	A.
Fuel (babul wood) 53 maunds,	...	...	...	...	...	...	13	0
Establishment,	...	...	...	...	...	...	9	8
Contingencies,	...	...	...	...	...	...	2	8
Total Rs.,							25	0

In 1878-79 the total cost of maintenance was Rs. 10,184, which gives a higher daily average than this, *viz.*, Rs. 28.

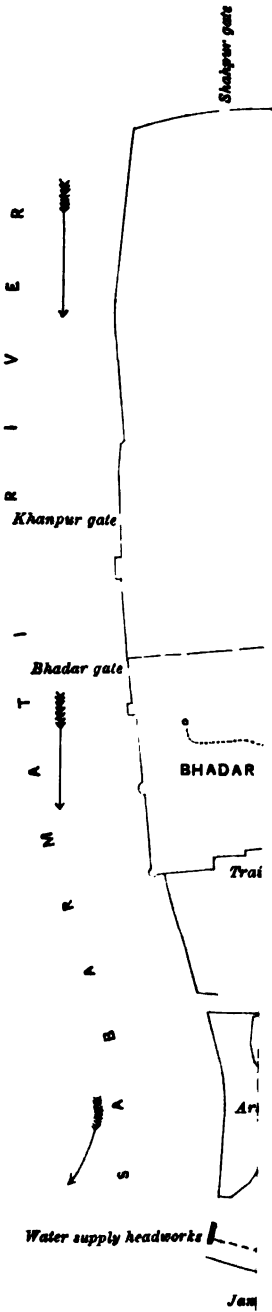
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PLAN (



WATER SUPPLY, AHMEDABAD.

Approximate Scale, 20 feet to an inch.

FIG. 1.

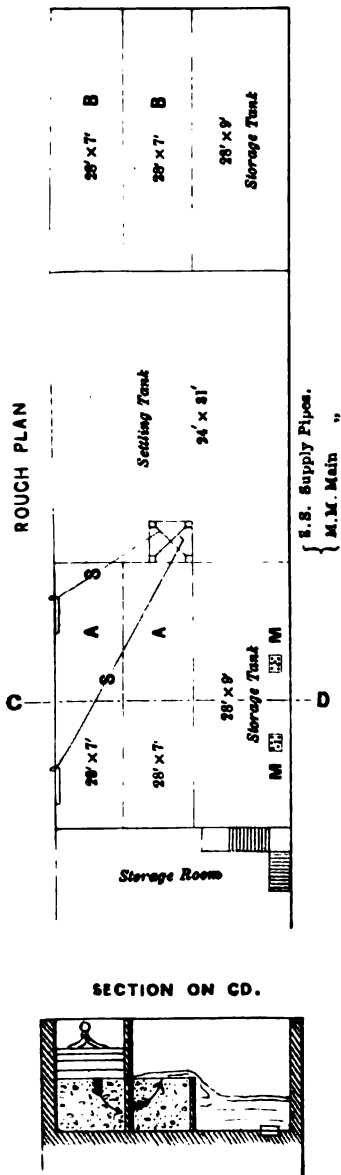


FIG. 2.

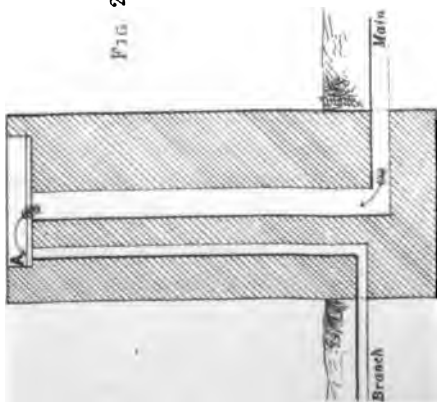
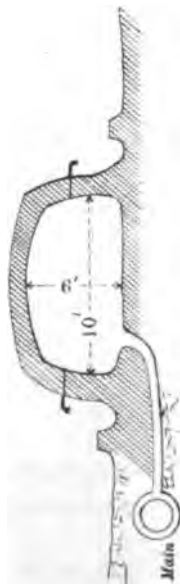


FIG. 3.



No. CCCXXXVI.

KARANDWAD WATER WORKS.

Cost, Rs. 23,807.

Karandwad is a town of 8,000 inhabitants at the junction of the Punchganga with the Krishna River, and is the capital of one of the Southern Marátha Country States of the same name.

It draws its water supply from the Krishna, 1 mile away on one side, and from the Punchganga at about the same distance on the other.

In 1866 the Chiefs of Karandwad offered the Political Agent, Southern Marátha Country, to spend a sum not exceeding Rs. 25,000 on works for the water supply of their town. Works were accordingly designed to fall within this limit, and to supply 5 gallons per head per day, a small wind engine of 3 horse-power, under an assumed wind pressure of 2 lbs. per square foot, available on an average for 7 out of the 24 hours throughout the year, was procured from England. With this it was calculated to raise 6,000 gallons per hour to a height of 50 feet. This was erected over a well sunk in the bank of the Punchganga at 385 feet from the low water channel. It has 8 sails, each of 35 square feet area, consisting of canvas stretched over a rectangular wooden frame, with a counter-weighted feathering arrangement, adjusted so as to feather the sails if the wind pressure exceeds what is considered safe.

The well is of 10 feet diameter and 35 feet deep, and in it the pump (double barrelled 7-inch cylinders) is posted somewhat above low water level of the river. The water is admitted to the well by a masonry culvert (2' x 5' in section), with plug or scraper with chains attached for drawing it back and forwards and so clearing out the silt.

The water is pumped into a stand pipe consisting of a masonry tower 20 feet high, built on the bank near the well, and thence it flows by

gravitation through a 6-inch pipe to the storage tank situated in the highest part of the town, a distance of $\frac{3}{4}$ mile.

Storage Tank.—The storage tank is an old one, forming part of the ditch of the old fort, to which nothing has been done. It has a capacity of 2,400,000 gallons, or about two months' supply. There is no system of distribution, the water being drawn direct from this tank.

The works were completed in 1869, but cannot be said to have proved a success. Owing to want of sufficient wind at other times, the wind engine only works regularly during the monsoon, and then, when the floods are high, it has to be stopped, as the structure is partially submerged by water, and $1\frac{1}{2}$ mile from shore.

It is constantly being stopped for repairs, about which there is great delay, partly on account of there being no skilled labour easily available.

The channel connecting the well with the river gets silted up and cannot be cleared until the river has somewhat subsided.

The storage tank leaks so that water cannot be accumulated in it.

During some months of the cold weather the engine works for an hour or two a day, and the inhabitants, living near the tank, draw their supply from a small masonry *hond* built in the bottom of the old tank, and into which the pipe discharges.

No. CCCXXXVII.

WATER SUPPLY, ADEN.

[*Vide Plate*.]

By LIEUT. H. CLARKE, R.E., *Exec. Engineer.*

THE water-supply of Aden has always been a matter of considerable difficulty owing to the scarceness of rainfall, *vide* the annexed extract from the register of rainfall at the Civil Hospital, Aden :—

Year.	1872-73.		1873-74.		1874-75.		1875-76.		1876-77.		1877-78.		1878-79.		1879-80.		Mean Average per mensem
Month.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	I.	C.	
April, ..	1	9	..	..	..	..	..	..	..	..	..	12	..	5	..	..	.16
May, ..	..	20	..	10	..	..	..	2	..	..	..	..	..	..	..	..	.04
June, ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.00
July, ..	..	41	..	2	..	..	..	..	..	..	..	..	..	..	..	3	.06
August, ..	..	98	..	27	1	58	..	..	..	14	..	..	..	22	..	15	.42
September, ..	..	21	1	28	..	..	..	..	..	64	2	73	..	..	..	46	.41
October, ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.00
November, ..	..	..	..	12	..	6	..	22	..	..	..	..	..	..	..	..	.06
December, ..	..	42	..	11	..	..	..	18	..	..	1	92	..	18	..	..	.40
January, ..	..	85	..	45	..	..	1	49	..	..	1	28	..	..	..	..	.58
February, ..	..	..	..	..	..	42	..	17	..	81	..	41	..	..	..	..	.26
March, ..	4	53	..	..	..	..	1	65	..	78	..	..	..	6	..	..	1.01
Total, ..	8	69	2	35	2	05	3	73	2	37	6	46	..	51	..	..	..

From the above it will be seen that rainfall may be expected generally in either March or September if at all. This register of course is no criterion of the actual rainfall on the hills, but will give an idea of the relative dryness of the years. It is, moreover, useless to take any water-supply projects which have been formed for Aden, to serve as guides in any respect with regard to India, because—

- (1). The exceedingly scanty supply from rain, the whole annual fall here would in most places in India be frequently exceeded in a few hours.

- (2). The fact that all the projects have been designed with a first view to the supply of Government employé's without any reference to outsiders. They are of course admitted to the benefit of any surplus, should there be any—a rare occurrence. In describing the supply, each source has been treated separately under a single head, and as far as possible, independent of any others. The relative order is as follows:—

1. Condensed Water-supply.
2. Wells.
3. Shaik Othman Duct.
4. Tawella Tanks Supply.
5. Kussoff Valley Scheme.

Condensed Water-Supply.

In 1867 Government became at last convinced of the absolute necessity of providing a plentiful and unfailing supply of *good* water for drinking purposes; and condensers were ordered out from England.

In 1869 one was erected at the Isthmus, and afterwards one at Seerah Island; an old river flat, the *Hydrabad*, was also converted into a floating condenser and stationed at Steamer Point. The above are the property of Government; but there are beside these other condensers, the property of private individuals and firms, which supply water to the public and the shipping (with the exception of the P. and O. Company's condenser, which supplies only its own Company's ships and employé's).

The need of these may be imagined from the fact that in former days the ships requiring water here have been some times compelled to pay as much as Rs. 8 per 100 gallons for brackish water brought in skins from Shaik Othman on camels.

Seerah Condenser.—This condenser house is built on the west end of the island, and is invisible from the sea-side. It was built in year 1871 at a cost of Rs. 12,900, exclusive of boilers and condensers. It holds two boilers and three Normandy's condensers, and the water was at first supplied from pipes laid in the sea. In the year 1874 an intake tank was excavated in the rock to prevent the pipes being choked with silt. It was 20 feet in diameter and 10 feet deep, and cost Rs. 900. In 1876-77 this tank was enlarged to three times its original size, to give a constant

supply of water—whether the tide was in or out, and cost Rs. 3,025. An additional boiler-house was built, and an old boiler used in Abyssinia was fixed and connected with the condenser at a cost of Rs. 1,820.

The water was formerly taken from the condenser in carts or by donkeys, &c. But in 1876-77 a cast-iron tank $40' \times 40' \times 8'$, holding 80,000 gallons of water in four compartments each 20 feet side, was erected in the vicinity of the European barracks. This holds a fortnight or three weeks' supply of drinking water for the troops. It is supported on masonry pillars, and roofed over with corrugated iron. Four-inch socket pipes are also laid to convey the water from the condenser to this tank—a distance of 3,200 feet. Sufficient head is given by pumping the water at the condenser to a height of 40 feet above the sea level into a cubic tank (iron) of 4 feet side, whence it gravitates to the condenser.

The cost of this work was Rs. 16,820.

These socket pipes had been lying at Aden since the expedition to Abyssinia, and had suffered greatly from exposure to the climate of Aden, which is peculiarly destructive to ironwork. They were, in fact, nearly, if not quite, worn out before being laid down, and have given constant trouble owing to leakage, both from the joints and through small holes in the pipes. New 4-inch flanged pipes are now being substituted for them at a cost of Rs. 5,000.

The evaporation from the iron tank must be very considerable. In testing the tank on one occasion with salt water before handing it over to the Commissariat Department, a fall of half an inch occurred in 24 hours, which could only be due to this cause.

Isthmus Condenser.—There are two condenser houses, each containing one boiler and condenser; they were built in 1857 and 1869 at a cost of Rs. 22,400. The water supply for condensing is obtained from a large tank ($250' \times 80' \times 7'$) excavated near the condenser at a cost of Rs. 2,000. This tank is situated almost half a mile from the sea, but the salt water percolates everywhere in the Isthmus, and is found at all depths, as will be seen hereafter, *vide* Wells. Two tanks built in four compartments each were erected in 1858 at a cost of Rs. 60,000, and are known as Nos. 1 and 2 Reserve.

Tanks.—No. 1 is not altogether devoted to condensed water, part of its compartment being occupied by Shaik Othman water. For particulars about size, &c., see table of Isthmus tanks on page 9. In 1876-77 pipes

were laid from the pier of obstruction to the condenser tanks; these pipes are of the same class as those laid from the Seerah condenser to the large iron tank in the Crater position, and have given like them a good deal of trouble. They also are being re-placed by new 4-inch flanged pipes at a cost of Rs. 5,400. They lead from a tower 20 feet high with a masonry tank of 2 feet side at the top, into which the water pumped through a 2-inch up pipe from the floating condenser, which is thus enabled to perform double duty.

Floating Condenser.—The old river flat *Hydrabad* was converted into a condenser and moored off the Post Office pier, Steamer Point. Opposite the end of this pier, tanks of stone and mud, cement plastered inside, are built to hold 45,700 gallons, at a cost of Rs. 4,500, and pipes laid to them from the head of the pier. Formerly an iron tank of four sides used to stand at the end of the pier, supported on cast-iron pipes, and the water used to be pumped from the *Hydrabad* into this tank, and thence flowed by gravitation to the tanks. In 1875-76 an addition was made to the length of the pier by a pier-head supported on iron screw piles, and the unsightly tank removed. The water is now raised to the head required on board the *Hydrabad*, and then flows through a vulcanized flexible tube into the pipes laid along the length of the pier.

The sizes of tanks are as under—

No of Tank.								Capacity. Gallons.
1,	...	...	...	...	...	...	...	17,400
2,	...	...	...	...	...	...	...	11,800
3,	...	...	...	...	...	...	...	17,000
Total, ...								45,700

In 1876-77 the old Municipal tanks under the Assistant Resident's house were repaired and roofed over. They are of stone and mud masonry, cement plastered inside, and have five compartments capable of holding in the aggregate gallons 103,832, *vis.* :—

								Gallons.
No. 1,	...	...	...	...	...	...	...	20,964
No. 2,	...	...	...	...	...	...	...	22,219
No. 3,	...	...	...	...	...	...	...	20,531
No. 4,	...	...	...	...	...	...	...	21,293
No. 5,	...	...	...	...	...	...	...	18,825
Total, ...								103,832

These tanks are connected with the other reservoirs at the Post Office pier by means of piping. These Municipal tanks, as might have been expected from their construction, have given frequent trouble by their leaking, and some have been strengthened by masonry counterparts. It would probably be found cheaper in the end to have built new stone and lime tanks than to have expended any money on these kucha arrangements.

The *Hydrabad* is now enabled to work both at the pier of obstruction and the Post Office pier. As soon as the tanks are full at one place she proceeds to the other. The above condensers are all Government property, and supply Government employes only; they are in charge of the Commissariat Department. The amount of water which could be produced at a *stress* is as follows :—

Per diem.				Gallons.
Seerah Condenser,	...	...	...	Government Property. {
Isthmus "	...	...	...	
Hydrabad "	...	...	...	
Total ...				21,600
P. and O. Company's Condenser,	...	...	...	Private Property. {
Luke Thomas & Co.'s	"	...	...	
Eduljee Maneckjee's	"	...	...	
Aden Coal Company's	"	...	...	
Total, ...				31,500
Total gallons, ...				53,100

Or a supply for 10,620 European troops at 5 gallons each per diem.

The cost of condensed water to the general public is about Rs. 3-8-0 per 100 gallons, exclusive of cost of carriage. The actual cost of production to Government is about Re. 1-12-0 per 100 gallons. It may be as well to add here a table of the allowance of water provided for its employes by the Government. Officers have to pay the carriage of their water, and also the cost of any extra water drawn by them.

Officer	each,	...	...	...	...	...	...	Per diem. Gallons.
		...	...	...	...	...	...	10
" wife	"	...	...	...	...	...	...	10
" horse	"	...	...	...	...	...	...	10
" child	"	...	...	...	...	...	...	5
" servant	"	...	...	...	...	...	...	5

						Per diem. Gallons.
For Mess (additional) each, ...	...	...	...	...	...	5
British soldier	"	...	...	...	...	5
" wife	"	...	...	...	...	5
" child	"	...	...	...	...	5
Native soldier	"	...	...	...	...	5
" wife	"	...	...	...	...	3
" child	"	...	...	...	...	1½
Public followers	"	...	...	...	...	3
Clerks	"	...	...	...	...	5
" wives	"	...	...	...	...	3
" children	"	...	...	...	...	2½

The average rate of cost of conveyance of water in the various parts of the position is as under—

Camp, ...	...	...	7 annas 2½ pies per 100 gallons.
Isthmus, ...	...	...	5 " 8½ " "
Steamer Point, ...	...	...	9 " 8½ " "

Water in addition to allowance is charged Rs. 3-8-0 per 100 gallons by Government, exclusive of carriage. Private firms can do this cheaper.

Wells.

These may be subdivided into two classes, *viz.* :—

- (a). Those within British limits, and
- (b). Those without British limits.

- (a) There are about 70 wells within British limits situated chiefly in the Biggaree and Aidroas Valleys, which are in charge of the Commissariat Department, water from which is supplied to the native troops and followers, cattle, &c. With very few exceptions the water is brackish in all of these wells. They average from 120 feet to 190 feet in depth, and in the best the water stands at a depth of about 70 feet below sea level. The sweetest water comes from the Banian well, situated near the old Residency and under the Kussoff Valley, which yields a daily average of 2,500 gallons. This is private property, the temperature of the water being 102° Fahrenheit. In the opinion of Lieutenant-General Wilkins, R.E., *vide* his Report, dated 13th January, 1857, the supply of water in the wells is due to rain and dew, and the wells are not artesian as was suggested at the time. Many attempts were made to ensure a supply of good water by boring, &c., after our first occupation, but with very

slight results. In the Isthmus salt water was met with at a depth of 245 feet below ground, and also in Biggarree Valley at a height of 70 feet above sea level. In this latter case the salt was probably due to saline deposits in the water-bearing stratum.

- (b). On the northern side of the harbour there is a piece of neutral ground (nominally British territory) called the Huswah, where the bed of a mountain torrent meets the sea. Sometimes, (though very rarely) after very heavy rainfall on the neighbouring hills, this torrent empties itself into the harbour; but in general it sinks into the bed of the river several miles inland.

From wells dug in the bed of this water course, a limited supply of water can always be obtained. It is brought over to the southern side either in boats or else in skins by camels across the Isthmus.

Water of fair quality is also obtained by wells near the village of Shaik Othman, and conveyed into Aden by camels. During the hot weather the Huswah and Shaik Othman wells supply a very large portion of the water used by the civil population, as about 3,500,000 gallons of water pass the Barrier Gate in a year. The Huswah water was supplied to the troops at Steamer Point for a short time this year, but has been pronounced by the Government Analyser, together with the Shaik Othman Duct water, to be utterly unfit for potable purposes, and the supply has since ceased. It, however, constitutes the chief supply of the poorer native population at Steamer Point.

The Shaik Othman Duct.

In the year 1867, the British Government entered into an agreement with the Sultan of Lahej, by virtue of which they gained permission to construct an aqueduct from two of the best wells at Shaik Othman to the British lines—a distance of between 6 and 7 miles. The British Government were to bear the expense of construction, and half the profits, deducting the working expenses, were to be handed over to the Sultan of Lahej's Agent.

The two wells are 10 feet in diameter and 25 feet deep, and are stoned with stone and lime masonry. The water is drawn from the wells by Burgess and Key's pumps, which are worked by one camel each; and is

pumped directly into the duct. These pumps can each supply about 24,000 gallons per day of 24 hours, if necessary.

The duct itself is a low masonry wall on which a channel 9" $\times$ 6" is built, and covered in with slabs set in mortar. The original intention was to follow the line of the old Bir Mahait Aqueduct, and make use of it as a foundation for the aqueduct; but it was found too unsafe to be used as a foundation. The duct is carried over the creek at Khore Muxar on a stone causeway, which does the double duty of carrying the duct and providing a roadway into the interior. The sides of the causeway are pitched with dry rubble masonry. The wall or duct is covered with earth rammed to a triangular section, and at intervals of about 1,000 feet is a small cesspit or cistern to catch impurities and to prevent earth from choking up the channel.

The duct terminates at the reserve tanks in the Isthmus, and the total cost was Rs. 2,96,933.

It was originally intended to extend the work up to Dharab, 8 miles further inland; and there to tap the torrent (already mentioned under the heading wells), and take advantage of the heavy rain during May, June, July, August and September on the hills, some 20 miles further inland.

There is a stone and lime masonry tank or expense reservoir at Khore Muxar, containing two compartments each 60' $\times$ 8' $\times$ 2½'. Each compartment holds over 6,000 gallons, and water for the Aden troop is supplied from here. Cost Rs. 5,000.

In the Isthmus there are four tanks of various sizes. They are built of stone and lime masonry and vaulted. The arches are gabled over, and the spandrils filled in with earth to keep the whole cool.

These tanks are capable of holding an aggregate of gallons 1,359,000, and cost Rs. 95,000.

They are all connected by pipes.

An estimate has been sanctioned by Government for laying pipes to connect the Tawella tanks with those of the Isthmus, so as to ensure a reserve of rain water in addition to that obtained from the condenser. This estimate amounts to Rs. 18,500, but has been put off until funds are available.

The quality of the duct water is brackish, and it has been condemned by the Government Analyser as unfit for drinking purposes.

It is issued to the troops for ablution, &c., and a limited quantity is sold to, and drunk by, the poorer natives who get it at Rs. 1 per 100 gallons. The Sultan of Lahej's half share of the profits amounts on the average from Rs. 1,000 to Rs. 1,200 per month. Until men are accustomed to drink the water, it is apt to produce bowel complaints.

An analysis of the water from the Shaik Othman Duct and also from the Huswah is annexed; also a table of the Isthmus tanks and their capacity and present occupation.

Extract from Report of Analyst on Water.

A.—Sample of aqueduct water, 1st June 1879.

B.—Water from Huswah, 2nd June 1879.

		A.	B.
Total solids in grains per gallon,	...	368.2	471.1
Chlorine in grains per gallon,	...	100.10	175.70
Free ammonia in parts per million,	...	.01	.32
Albd. ammonia in parts per million,	...	.07	.08

Sediment—

A.—Copious vegetable debris, *Paramacia auquellile*.

B.—Copious vegetable debris, *Actenophrys sol. eutomatrea auquellile*.

Extract from Sanitary Commissioner's letter.

2. "Of the two samples, that marked A can be used for ablution, and it might be used for cooking. Sample B can be used for ablution, but it is not recommended for cooking."

3. "Obviously neither sample is fit for drinking."

List of Tanks in Isthmus.

Locality.	Number of compartments.	Size of each Compartment.		Height to spring in of arch.	Capacity of each tank in gallons.	Remarks.
		Z	B			
Victoria Bastion Reserve Tank,	8	100	10	8½	891,000	Shaik Othman water.
Expense	6	60	8	2½	88,000	
Near "N. I. Lines No. 1 Reserve						} Part Shaik Othman,
Tank,	4	44	42	8½	810,000	
Near Condenser No. 2 Reserve						} and part fresh water.
Tank,	4	44	42	8½	810,000	
Condensed water.						
Little Isthmus No. 8,	4	44	42	8½	810,000	Shaik Othman water.
Khore Muxar,	2	60	8	2½	12,000	" " "

List of Tawella Tanks showing their Capacity in Gallons.

	Number of Tank.	Contents.	Remarks.
Government Tanks, ..	1	1,255,424	Coghlan Tank.
	2	64,881	
	3	21,011	
	4	160,987	
	5	185,919	
	6	70,944	
	7	896,964	
	8	4,645,278	
	9	210,000	
	10	128,786	
	11	828,501	
Rented to Páris and Natives, ..	1	7,418,690	Playfair Tank. Páris Tank.
	No. 1 to 8 {	2,835,000	
		500,000	

Tawella Tanks.

There is no certain record of the date of the construction of these tanks, which were, however, probably constructed about the date of the second Persian Invasion of Yemen, A.D. 600. In the centre of the Peninsula of Aden is a range of hills, which rises almost perpendicularly to a height of 1,760 feet, and forms the wall of the Crater of Aden. On the western side the hills are very precipitous, and the rain water descending from them is carried rapidly into the sea. On the interior or eastern side, though the hills are equally precipitous, the descent is broken by a large table-land, which occupies about one-quarter of the superficial area of Aden. This plateau is intersected by numerous ravines, which converge into one or two valleys, which thus receive the largest part of the drainage of the Peninsula. The steepness of the hills and the scantiness of the soil prevent a great amount of absorption, and thus a moderate fall of rain causes a rush of water, almost amounting to a river, before it reaches the sea.

To collect and store this water these tanks were constructed. They are very fantastic in their shapes. Some being formed of a dyke built across the gorge of a valley: in others the soil in front of a re-entering angle on the hill has been removed, and a salient angle or curve of masonry built in front of it; while every feature of the adjacent rocks has

been taken advantage of, and connected by small aqueducts to ensure no water being lost. The overflow of one tank has been conducted into the succeeding one, and so a complete chain has been formed, reaching to the town. There is a tradition that about A.D. 1500, the then Governor had succeeded in reaching sweet water in wells dug by him, and in consequence allowed these tanks to go to ruin. This they would very soon do from action of *débris* washed down from the hill sides; there being no shield bunds.

The rainfall of 1859, when the tanks were in process of restoration, though the channel for about quarter mile had been cleared, brought down such a mass of *débris* as nearly to fill No. 1 tank.

Altogether there are about 50 tanks, which, if all cleared out, would hold an aggregate of about 30,000,000 gallons. Those actually in use number about 18, with a capacity of 10,753,690 gallons. The restoration of these works was commenced about 1854 by Captain Playfair, Assistant to the Political Resident, and the expenses were met by the Municipal Funds, and the money realized by the sale of water. In 1857 the charge of their restoration was handed over to the Executive Engineer, Aden.

In 1859 the Executive Engineer, Aden, (Major-General Fuller, R.E.,) found it necessary to add a shield bund above No. 1 tank, to prevent the *débris* from the valley being washed into the tank. Experience gained by a heavy fall of rain after this, induced him to raise this first shield bund to a height of 35 feet instead of 15 feet as at first, and to add a second shield bund above this (1860), and in addition at the necks of the water-courses other bunds were constructed (all with gratings at the bottom) to resist the rush of *débris* brought down from the Shum Shum Range.

These upper bunds were all placed at narrow necks, and their sites being tolerably level above the bunds, facilitated the removal of *débris* to either side,—a thing which in the lower bunds would have proved a matter of considerable difficulty, owing to the precipitous character of the valleys. All these bunds are of stone and lime masonry, with gratings in the bottom to allow water to pass when it has rained slightly, before it can be absorbed by the rocks. The tanks are all plastered excavations, varying in depth from 10 feet to 60 feet. Each tank is connected with the succeeding one by an open or covered duct, and as

soon as one is full, the water is conducted to the next until the entire system is full; and when the last (Playfair tank) has received its supply, the surplus water is carried to the sea by a channel 60 feet wide, the sides of which are of dry rubble (slope 1 to 1) with a masonry coping; across it at every 30 feet masonry bunds are run below the surface to save the bed from scouring.

The plan of Playfair tank is somewhat remarkable. It is built in a series of rings or offsets, rising about 5 feet each, and the tread being 1 foot.

There are two places where these offsets have been omitted to facilitate the drawing of water. Over each a pulley can be arranged for hoisting a bucket. All the tanks are furnished with flights of small steps, constructed where convenient or necessary, and a bridge across Coghlan tank gives access from one side of the ravine to the other. Coghlan tank, the largest of the Government tanks, holds 4,645,273 gallons, and has its side cemented and floor asphalted. It is perhaps worth noting that the No. 1 shield bund built by Major-General Fuller, R.E., in 1859 re-paid its cost in the first heavy fall of rain by preventing accumulation of *débris* in No. 1 tank.

The cost of removing this after the storm of September 1859 was Rs. 4,509-6-6, and the cost of the bund then erected Rs. 2,235-0-6. Since their restoration these tanks have only three times been filled, *viz.*, in May 1864, in May 1870, and in September 1877. The heavy rainfall of 1872-73 did not entirely fill them. During such times as there may be water in the tanks the camp condenser is not worked.

The water collected is issued for the use of the troops, and is also sold at Re. 1 per 100 gallons. In September 1872 a rainfall of 2.75 inches fell in one hour, and an hour afterwards all the tanks were full, and a large quantity of water passed off into the sea.

The Playfair tank is leased by Government to some natives. It holds 2,835,000 gallons, and its owners are bound by the terms of their lease not to exceed the Government rates for the sale of water.

The total cost of the restoration of these tanks has been to Government Rs. 3,60,000.

Kussoff Valley Lakes.

Projects for the construction of reservoirs in the valleys overhanging the Banian temple have been constantly brought forward since 1845. Detailed plans and estimates were first worked out by Captain (now

Major-General) Fuller, R.E., in 1861. On his original design the work, as it now stands, has been based, though various modifications have been from time to time introduced in the several revisions of the scheme, until the one finally sanctioned in August 1873, which was prepared by Major Ducat, R.E. Major-General Fuller, R.E., proposed to build three main dams with shield bunds above them, and a tunnel in the rock through the side of the valley to act as a waste weir. He also proposed to build an expense reservoir near the old Residency, and to have pipes connected with the covered reservoirs in the Isthmus position. The subject of the thickness of the masonry in the main bund (No. 8) was discussed at some length by Government. In consideration of the frightful destruction which would ensue should this bund fail, Government decided to have the bund made 18 feet thick at the top and 42 feet at the bottom, with a mean thickness of half its height (*i.e.*, 30 feet) as against the section proposed by General Fuller, R.E., which was 12 feet top and 27 feet bottom thickness.

Captain Pym, R.E., revised the plans in accordance with orders received from Government in June 1864, and proposed doing away with the tunnel weir into the Biggaree Valley, and the extension of the piping to the Isthmus.

He considered that the tunnel weir would be so seldom if ever required that it was not worth while going to the extra expense. His revised estimate amounted to Rs. 2,14,993.

Captain Mander, R.E., in revising retained Captain Pym's sections of the dams, added by order of Government an extra dam below No. 3, to impound water for building purposes; reverted to General Fuller's waste water tunnel weir, and altered the intake head works to the supply sluice; he preserved Captain Pym's single reservoir near the Residency, and adjusted the rates, thereby making estimate amount to Rs. 2,92,723. Major Ducat's final revision amounted to Rs. 3,75,821. The general scheme submitted consisted of three large tanks and one small one on the plateau below Shum Shum. Bunds were to be built across the valley, and shield bunds across the water courses leading into the tanks, to prevent the accumulation of deposit. The small bund was intended to assist in the collection of water to help to build the other bund (No. 3). The two main tanks were to be connected by pipes, and from No. 3 the supply of the garrison was to be drawn. The total contents of the three

tanks was estimated at 5,697,120 cubic feet. The works proposed consisted of the following :—

No. 1 Shield Bund—height 30 feet, width—top 9 feet, bottom 21 feet. Estimated cost Rs. 9,056.

No. 2 Shield Bund—width—7·5 feet top, 17·5 feet bottom, height 25 feet. Estimated cost Rs. 8,670.

No. 1 Main Bund—width—15 feet top, 35 feet bottom, height 50 feet. Estimated cost Rs. 46,922. Capacity 1,419,600 cubic feet. Cubic feet per Rupee 30.

No. 2 Main Bund—width—top 20·5 feet, bottom 47·5 feet, height 68 feet. Estimated cost Rs. 1,21,255. Capacity 706,320 cubic feet. Cubic feet per Rupee 6.

No. 3 Main Bund—width—top 18 feet, bottom 42 feet, height 60 feet. Estimated cost Rs. 1,27,628. Capacity 3,571,200 cubic feet. Cubic feet per Rupee 27.

Extra Bund—Rs. 4,596, piping Rs. 17,827; expense reservoir Rs. 4,275, tunnel Rs. 15,696.

On submission to Government, No 2 dam was rejected as not yielding results commensurate with its cost, and No. 2 shield bund was also directed to be omitted. It was proposed in the first place to carry out a portion of the work only, *viz.*, No. 3 bund to be carried to a height of 30 feet only instead of 60 feet as in the complete project. No. 1 shield bund, the extra bund, and expense reservoir and iron piping were included in this estimate, which amounted to Rs. 1,08,777. In carrying out this portion of the scheme (the only portion as yet completed) the extra bund was abandoned, as the solid rock on which it was to be founded was not met with until at a depth of 15 feet below ground, which would have brought its cost up to Rs. 12,484; it had also from the first appeared doubtful, if it would have answered its purpose, when completed; owing to the shattered nature of ground overhanging the Banian well, near which it was proposed to place it. Considerable doubt was felt as to whether the bottom of the tanks would hold water; and it was with a view to test this that No. 3 dam was only completed to a height of 30 feet in the first instance.

Both Captain Mander and Major Ducat thought it would perhaps be found necessary to plaster the bottoms of the tanks at a probable increase of expenditure of about Rs. 2,00,000 at least. In addition to this the

latter expressed a doubt whether a sufficiency of rain would fall to fill the tanks and keep them filled.

Even such an exceptional fall as 7 inches, *making no deduction for absorption*, would not fill the three tanks. This was one of the reasons for the abandonment of No. 2 main bund.

As regards the construction of the bunds, the foundations were carried down to solid rock, the lower foundation being built in Portland cement, as also is the whole of the front and back of the wall (including the steps in the sides). The face stone being dove-tailed.

The hearting is built in pumice and lime mortar, without horizontal courses, the work being *vertically* bonded, so as to obviate leaks through the dam.

In the bottom of the bund is a tunnel arched over, in which the pipes are laid and covered over to prevent the scour through the sluice, when open, destroying them, while at the same time it allows of the pipes being examined at any time with perfect safety.

The inner mouth is fitted with a sluice door which converts the tunnel into a waste weir.

An isolated water tower is not provided, but instead a semi-circular well or cistern with walls 4 feet thick has been built on in front of the dam. At every 10 feet in height are bell-mouthed bent pipes fitted into the circular portion of the wall to fill the well.

The valves are cast-iron, covered with leather, which fit into the bell-mouths, and are raised by chains attached to a 6-ton crab winch which also works the sluice in the tunnel. In case of an emergency if all the valves are opened and the sluice gate also, it is calculated that the head of pressure on the dam can be reduced 10 feet in about 8 hours, which should be sufficient. The full section is completed up to a height of 80 feet, including valves, tower, &c., but as an additional precaution for the present, the centre 20 feet of the dam is raised 5 feet above the rest, the side portions being paved so as to act as weirs. The centre portion unpaved will thus prevent the overflow water falling on the pipes. When the bund is being completed the paving will be removed, and re-laid on the top of completed bund.

The expense reservoir is simply a small tank house, capable of holding about 2,000 gallons, and is above ground, so that water can be issued from outside by a stop-cock.

The portion of the project sanctioned was completed in 1875, and in September 1877 a fall of 2'-75" filled No. 8 tank to a height of 28 feet, but it all disappeared in 36 hours' time.

No appreciable difference was noticed in the height of the water in the wells underneath at the time, but it perhaps eventually percolated into them. Under any circumstance by the stopping of this large body of water great damage to the buildings was avoided. For instance, in former years, after a heavy fall, General Fuller, R.E., reported the Executive Engineer's office full of water up window sills, *viz.*, 2 feet.

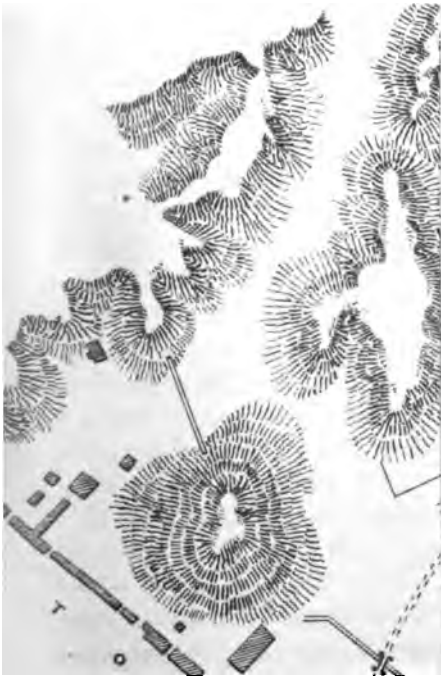
It appears on the whole unlikely that Aden will be able to dispense with any of her existing sources of water-supply.

It is true that it is said that the climate is gradually changing, but as yet we have not achieved an annual rainfall. Nor do we seem likely to get it. Without a regular and comparatively heavy rainfall there seems a probability of the Kussoff Valley lakes remaining for the greater portion of their time empty.

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No. CCCXXXVIII.

INCHALKARANJI WATER WORKS.

Total cost, Rs. 1,11,174.

Inchalkaranji is a town of about 8,000 inhabitants, situated about 17 miles east of Kolhápur on the north bank of the Punchganga river, and is the capital of a Jahagir of the same name feudatory to Kolhápur.

Its water supply has hitherto been from wells, and from the river about one mile from the town.

A design for supplying the town with water, at the rate of 5 gallons per head per day, pumped from the river by means of a wind engine, was made by Major Mant, R.E., and carried out by Major Ducat, R.E., with some modifications made by the Superintending Engineer, Southern Division, as to the position of the wind engine.

In the original design the wind engine was to have been erected on the bank and pumped from a well, but from experience of a similar work at Karandwad, it was decided that the pumps should work directly over the river, so a masonry tower 35 feet high was built close to the edge of the low water stream; its top, a few feet higher than the river bank, and on this the iron cross braced framework (30 feet high to axis shaft of sails) of the wind engine was erected.

The latter was calculated to give 6 horse-power with a wind pressure of $1\frac{1}{2}$ lbs. on the square foot, which pressure was assumed to be available on an average 6 hours out of the 24 throughout the year. This assumption proved to be excessive, and such a pressure for such a daily duration could only be obtained during the height of the south-west monsoon. The pumps are 6-inch treble barrellled, and have to lift 80 feet, 18 feet of this by suction.

The water is pumped first to its full lift of 80 feet into a stand pipe consisting of an iron cistern or box raised on an iron cross braced tripod 50 feet high, erected on the river bank, of which two legs form respectively the up and down pipes. The water flows from the stand pipe by gravi-

tation through a 7½-inch main, a distance of 1½ miles to the storage tank situated in the highest part of the town.

This storage tank will hold 1,200,000 gallons, one month's supply for the town, and was formed by enlarging some old quarries, lining their sides with masonry and puddling the bottom. Before entering the tank, the water passes by upward filtration through a filter bed of two compartments for alternate use. The filtering medium, 4 feet thick, being of layers of broken stone, gravel and sand.

Distribution.—The water is drawn off from the storage tank by bell-mouthed intake pipes at various levels which pass into a valve well, from which the 5-inch supply main carries it into the town, and by various branches supplies four square masonry *kouds* or dipping wells 13' × 6' × 3' each of two compartments, for use by different castes, and two cattle troughs, distributed about the town. The discharge into each of these is regulated by a ball-cock.

The works were completed in 1876, but after two years' trial it was found that, except during the south-west monsoon, the wind at Inchalkaranji was totally insufficient to work the wind engine, even though after the first trial its original sail area had been considerably increased. It was determined therefore to replace the wind engine by one of Tangy's vertical boiler, 8 horse-power high pressure steam engines adapted to burn wood fuel. To place this above the level of highest flood, the masonry tower in the river was raised 12 feet, and an engine room built on top, the engine and gearing being carried across the hollow interior of the tower by three wrought-iron girders. This work is now all but complete, and the engine about to be tried. It is calculated to raise 11,000 gallons per hour, and so give a supply of 10 gallons per head per day by working eight hours per day.

No alteration has been made in the rest of the works.

	Ra.
Cost of masonry tower in river,	11,916
" wind engine and pump,	14,404
" rising main 7½-inch cast-iron pipes,	22,358
" replacing wind engine by steam engine,	10,235
" storage tank,	23,509
" distribution by iron pipes, including valves, &c.,	20,637
" masonry <i>kouds</i> or dipping wells and cattle troughs,	8,115
Total,	1,11,174

No. CCCXXXIX.

DESCRIPTIVE ACCOUNT OF THE SYSTEM OF WATER SUPPLY BY MEANS OF STEAM PUMPING FOR THE EUROPEAN TROOPS OF THE HYDERABAD SUB- SIDIARY FORCE AT SECUNDERABAD.

By CAPT. H. C. FOX, R.E., *Exec. Engineer, Secunderabad Division.*

THE European troops of the Hyderabad Subsidiary Force, stationed at Secunderabad, in the Deccan, consist of:—

				Men	Officers.
1 Cavalry Regiment,	...	...	...	594	80
1 Battery Horse Artillery,	}	...	...	675	80
2 Light Field Batteries,					
1 Heavy Field Battery,					
2 Infantry Battalions,	...	...	...	2,450	80
				3,719	140

and are located, except the Heavy Field Battery, in permanent barracks, which, within the past 25 years, have been gradually constructed on the high ground known as Trimulgherry, which lies to the north of the town of Secunderabad. The barracks are now complete except a portion of those required for the Heavy Field Battery, pending the construction of which, that battery is quartered at Secunderabad, and a few subsidiary buildings for the completed barracks. A system of water supply for these barracks, by means of steam pumping from wells into service reservoirs, whence the supply is distributed in the usual manner by piping, has recently been completed; and the following is a general description of the system and of the results of its working.

The site may be generally described as a plateau running north and south, about 4 miles long and about $1\frac{1}{2}$ mile wide, the highest part

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being at the north, and about 1,800 feet above sea level. The plateau is a spur of the watershed ridge between the rivers Godavery and Kistna, and apparently has but little less elevation than that of the watershed ridge, although the plateau is distant about ten miles south of the actual watershed line. As might be expected under such conditions, the only way of obtaining a permanent water supply at Trimulgherry is by means of wells; and fortunately no difficulty in thus obtaining a sufficient supply for the new barracks has been met with. The geological formation of the site is the same as that found throughout the most part of the Deccan, namely, "Syenite" granite, the surface of which has undergone, and is probably still undergoing, slow decomposition under atmospheric influences, the result being that the inequalities of the rock surface have become filled with beds of "moorum," interspersed with rounded "cores" of granite which have resisted decomposition. The annual rainfall averages about 30 inches; and on most places in the Trimulgherry plateau wells sunk in the moorum have a water level of 15 feet below surface at the end of monsoon, and 35 feet at the end of the dry season, *i. e.*, in ordinary seasons.

Sources of Water supply in use by the Troops.—As the different sets of barracks were built, about four wells per regiment were sunk in the regimental lines, and the water supply from these wells, supplemented in exceptionally dry seasons by water carried from more distant sources, was, it is believed, always found sufficient for all regimental purposes. With a view, however, to ensure a regular and pure supply of water for purposes of drinking, cooking, and washing, in connection with the troops, a system of water supply by steam pumping from two specially constructed wells was undertaken about ten years ago, and was completed last year. The number of persons supplied is shown above, and at 16 gallons per man and 80 per officer, this gives a total quantity of water—70,704 gallons—supplied daily. The supply has been found to be ample though not excessive. The adequacy of supply from the two new wells was tested by prolonged trials, in one well lasting 343 days, water being pumped from the wells and passed through meters. The supply was found to be sufficient, and the purity of the water very satisfactory. The old wells are now used for filling plunge baths, watering horses, and providing water for tatties and gardens, and for flushing drains, &c. The system was constructed in two sections; the first or south water supply

being commenced in May 1867 and taken into use in May 1874, while the second or north water supply was, except the construction of the well, taken in hand in 1878 and completed in 1880. The two systems will be described separately.

South Water supply.—The south water supply well with its main service reservoirs, and distributing system gives water supply to one of the Infantry Regiments and to the double-storied hospital, which is used by both Infantry Regiments. The well is cylindrical, 30 feet in diameter, and 55 feet deep below surface of site, and is steined with granite, built without mortar where springs occur. Above ground the well is provided with a parapet and a domed roof of zinc on iron frame-work. Water is pumped from the well by machinery, to be described hereafter, to two service reservoirs at different levels, whence the supply flows by gravitation to the taps, whence it is drawn for use. The high level reservoir supplies the hospital and the officers' quarters, while the low level reservoir supplies the men's barracks and the family quarters. The necessity for thus dividing the supply arises from the levels of the ground. The upper storey of the hospital is at too high a level to be supplied by gravitation, but receives its supply from a small reservoir in the lower storey, whence water is pumped by hand to cisterns in the upper storey.

Pumping machinery—Tangye and Holman's Special Pumps.—The pumping machinery originally fitted in this well consisted of a pair of Tangye and Holman's special direct acting steam pumps with vertical cross tube boilers, the pump and the boiler being fixed on the same bed plate in each set (for full description and drawing of this arrangement see Section E., page 29 of Messrs. Tangye and Holman's catalogue of 1867), the diameter of the steam cylinders being 7 inches, that of the water cylinders 5 inches, and the length of stroke 12 inches. The boilers were fed by miniature special pumps fixed to the bed plates, and each set of this machinery should have been capable of pumping 5,000 gallons of water per hour. The machinery was placed in a masonry shaft close to the well, the pumps being about 30 feet above the bottom of the well, and 25 feet below the surface of the ground. A U-shaped stand pipe, the summit of which was a little above the level of delivery pipe at high level reservoir, was fixed on the delivery main, and provided with a cross pipe and valve at the level of the low level reservoir delivery, so that it could be used with the latter.

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The whole of this machinery proved unsuccessful in use, and was removed after about a year's trial. The machinery was supplied before the railway was opened to Secunderabad, and its failure was, no doubt, partly due to there then being no fitters and engineers locally procurable and having knowledge of the structure and management of pumps of the above description. Moreover, the boilers being placed in a pit 25 feet deep, and only about 16 feet wide, the heat in the pit was very great; and it was found that the engine driver and firemen could not attend properly to their work when the boilers were under steam. The pumps worked fairly well, except that the reversing tappet valves (*see* page E-32 of Tangye and Holman's catalogue) were very apt to stick and stop the pumps; but the small feed pumps, owing to the extreme smallness of their working parts, could not be kept in working order, and there was consequently always danger of low water in the boilers. The latter defect was remedied by attaching injectors to the boilers, but nevertheless, as, on the whole, the machinery was evidently unsuited for its purpose, it was eventually decided to remove the machinery altogether. One defect in the pumps was the loud banging noise they made at every stroke, which caused great annoyance to the officers whose quarters are near the well.

Ransome and Rapier's pumps.—The pumping machinery now consists of a pair of Ransome and Rapier's double-acting lift and force pumps. Each of these is driven by rods and gearing worked by a small engine and vertical boiler placed on the surface level close to the well (for a drawing and description of this arrangement see in *Spon's Engineering catalogue*, page 79). The size of the pumps is—diameter 6" $\times$ stroke 12", that of the steam cylinder, diameter 8" $\times$ stroke 10". The boilers are placed in a fairly spacious engine house; and the pumps are in shafts 25 feet above the bottom of the well. This machinery has worked well since 1875. The amount of water which can be delivered per hour depends much on the depth of the water in the well, and on the quality of the fuel supplied by the Commissariat Department; but, speaking generally, it may be said that one pump can fill the two service reservoirs with 72,000 gallons, or three days' supply in about fifteen hours, or, say, two days' pumping. This gives an average delivery of 5,000 gallons per hour for one pump. One pump only is worked at a time, the other being kept as a reserve in case of a break-down, or when

repairs are necessary. The supply is delivered into the service reservoirs by a 4-inch main to the high level, and a 5-inch main to the low level.

The high level main is always kept open, and is provided with a short open vent at its summit, so that it acts as a stand pipe. The old stand pipe has been taken down.

Reservoirs.—The reservoirs are rectangular masonry chambers half sunken in the ground, and flat roofed with massive granite slabs. Each reservoir has two compartments, so that the supply may be kept up should the reservoirs require repair or cleaning. The masonry of the reservoirs is of granite in lime mortar, plastered inside with Portland cement. The sides are protected with earthen banks, and the roofs are made water-tight with plaster. These reservoirs serve their purpose very well.

Distributing Mains and Piping.—The contoured plan* shows the system on which the distributing mains and piping are laid. The diameters of the pipes were determined by calculation, Hawksley's formula being used. The mains are composed of cast-iron socket pipes with turned spigots and sockets, and are laid as much as possible in trenches $1\frac{1}{2}$ feet below the surface of the ground. The main from the high level reservoir commences with a diameter of 4 inches, which is gradually reduced to 3 inches. The diameter of the main from the low level reservoir is 5 inches reduced to 3 inches. The supply to the several buildings is delivered from the mains by wrought-iron screwed piping, of diameter 2 inches diminishing to 1 inch, and from this piping the water is drawn by cast-iron galvanized plug taps.

The mains end in "wash out" valves; and the supply to each building can be cut off or regulated by valves on the branches and mains.

It may be noted that brass taps and lead piping originally fixed in this system were found unsuitable, as these fittings were frequently stolen by the natives employed at the barracks. "Spring careless" taps and screw "waste not" taps were also tried and found unsuitable. A plain cast-iron plug tap, or bib cock, appears the best pattern for use in barracks.

The cost of the south water system was Rs. 85,060. The monthly cost of working is Rs. 380.

North Water supply.—The other system, known as the north water

* Not published.

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supply is almost precisely similar in design to the south water supply, but on a much larger scale, inasmuch as it has to supply

- 1 Regiment Cavalry,
- 4 Batteries Royal Artillery,
- 1 Regiment Infantry (except hospital).

The contour plan will show the positions of the main well, service reservoir, mains and piping, and that of a supplementary source of supply from an old well in the Cavalry Lines, known as the quarter-guard well. This supplementary supply was included in the system while the project was being worked out, and practically most of the supply for the Cavalry regiment is drawn from this source. The quarter-guard well system has been connected with that of the main well, so that the Artillery and Infantry can also be supplied from the quarter-guard well for a few days, should it be necessary to close the main well for repairs or cleaning out.

Machinery.—The pumps and engines at the main well are of the same pattern as those now at use at the south water supply. There are three engines and pumps of this pattern at the main well, or five sets in the north and south water supply together. The parts are interchangeable, and a reserve of spare working parts kept in store, so that in case of damage, repairs can be effected without any delay. Two sets of pumps worked at the same time can deliver about 10,000 gallons per hour in the reservoirs.

The machinery at the quarter-guard well consists of a pair of traction engines, which were used during the construction of the new barracks but are no longer required for that purpose. The engines have been dismantled and fixed in a small engine house. Each drives a treble barrel force pump (of pattern shown on page F-9 of Tangye and Holman's catalogue) by means of a belt from the fly-wheel of the engine to a pulley on the crank shaft of the pump. The machinery works well, and each set delivers about 3,000 gallons per hour.

Dimensions of the engine and pump are as follows:—

	Inches.
Diameter of cylinder,	10
Length of stroke,	12
Diameter of pump barrel,	3
" suction pipe,	3
" delivery main,	3
" " " " " " " " " " " "	4

Maximum steam pressure 50 lbs.

Reservoirs—Are solid masonry raised on arches and covered with light iron roof, and are very convenient and serviceable.

Delivery and Distributing Mains and Pipes—Are of the same description as those in the south water supply. The requisite diameters were calculated by Hawksley's formula, and the flow in the pipes is all that can be desired.

There is no stand pipe in this system—except an air vent in the connecting main between the two wells which crosses a ridge—the delivery main to the highest reservoir being always kept open. This main acts as a stand pipe.

The cost of the north water supply system was Rs. 2,27,852. The monthly working cost Rs. 500.

General remarks applicable to both systems.—At each pumping station there is an enclosure with a high wall and strong gate, necessary to keep soldiers and natives from approaching the wells and machinery. Each enclosure contains the following buildings:—

1. Engine house.
2. Quarters for engine driver.
3. Shed for fuel (corrugated iron on pillars).
4. Small shed for ashes.

At the north water supply, quarters for the native establishment have also been provided outside the enclosures. This is a convenient arrangement, and unobjectionable so long as the cleanliness of the ground around the quarters is insisted on. To help to this end, latrines, known as Crawford's rural privies, and rubbish receptacles have been provided with good effect.

At the north water supply well also, the open tops of the wells are protected with wire netting to keep out birds, leaves, &c., and this seems a desirable arrangement.

The efficiency of the working depends much on the quality and dryness of this fuel, but in these respects the fuel is generally satisfactory; and experiment has proved that at Secunderabad wood fuel is considerably cheaper than coal for use in stationary engines.

The monthly cost of working of the water supply is nearly the same as the saving on account of regimental water supply establishment, dispensed with on the completion of the steam water supply. But probably the quantity of the present supply is several times greater than that of

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the former, while, without any doubt, the present supply is more certain and more pure.

To the cost of mere working, however, it is fair to add the following annual charge in considering the financial result of the steam water supply :—

	Ra
Interest at 4 per cent. on Ra. 3,12,000, the total cost, ...	12,480
Deterioration at 3 per cent. on Ra. 1,75,000, the approximate cost of piping and machinery,	5,250
Occasional and petty repairs, say,	700
Total, ...	18,430

Statement showing cost of Reservoirs and of 1000 gallons of cubic contents and of daily supply.

Name of Reservoir.	Cubic content being 3 days' supply.	Cost of Reservoir.	Cost for 1000 gallons of cubic contents.	Cost for 1000 gallons of daily supply.	Height of delivery above mean water level in well.
<i>South Water Supply.</i>					
High level,	6,080 × 3 = 18,240	Not known	Not known	Not known	130
Low level,	18,080 × 3 = 54,240	Do.	Do.	Do.	85
<i>North Water Supply.</i>					
Cavalry officers,	2,400 × 3 = 7,200	2,566	356	1,069	139
Cavalry barracks,	9,504 × 3 = 28,512	5,801	203	610	104
Royal Artillery & Infantry officers,	5,600 × 3 = 16,800	4,381	291	873	67
Royal Artillery barracks,	10,800 × 3 = 32,400	5,151	159	478	81
Infantry barracks,	18,240 × 3 = 54,720	8,714	159	478	67

SECUNDERABAD, }
3rd February, 1880. }

H. C. F.