MUSSOORIE

HYDRO-ELECTRIC SCHEME.

COMPLETION REPORT.

VOLUME I.

THE

COMPLETION REPORT

OF THE

MUSSOORIE HYDRO-ELECTRIC SCHEME

**Compiled in the Office of the Chief Engineer to Government,
United Provinces, Public Works Department,
Buildings and Roads Branch.**

VOLUME I.—REPORT.

ALLAHABAD:
PRINTED BY W. C. ABEL, OFFG. SUPDT., GOVERNMENT PRESS, UNITED PROVINCES.

Price—Vols. I and II—Rs. 13-8-0 (20s. 3d.)

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CHAPTER I.

INTRODUCTORY AND FINANCIAL.

Mussoorie, a hill sanitarium and municipality, is situated in north latitude 30°27′ and east longitude 78°61′, seven miles from Rajpur, at the foot of the hills, and fourteen miles from Dehra, the terminus of the railway. It lies on the first range of hills running east and west and on lateral spurs thrown out to the north and south. Its elevation varies from 6,000 to 7,000 feet above sea level and its area is 22 square miles. The season usually covers a period of some six months from April to September. The population is consequently variable being at the summer census of 1910, 17,420 and at the census of March of the following year, 6,552. The houses, like those in other hill stations in the Himalayas, are scattered about the hill sides as the configuration of the mountain permits. The greater number are to be found in the central portion of the station and, except in this part, the place is well wooded. The roads, which are winding and narrow, total sixty-one miles and are maintained by the municipality which is administered by a Board composed of 11 elected and 3 appointed members, with the District Magistrate as Chairman. Mussoorie is connected with Rajpur by both a bridle and cart-road, the former being seven, and the latter fourteen, miles in length. Mussoorie.

The principal taxes are tolls levied on persons entering the municipality bringing in Rs. 90,000; house tax, Rs. 39,000; conservancy and capitation taxes, Rs. 26,000 and miscellaneous taxes such as dog, rickshaw, and house taxes, &c., Rs. 13,000. Taxation worked out to about Rs. 7-7-9 per head in the year 1902-03 but as a result of the demand for improved sanitation and the additional expenditure incurred in carrying out the scheme referred to in this report, the incidence rose in 1910-11 to Rs. 9-7-6 per head. This rate in the same year in the hill stations of Simla, Naini Tal, and Darjeeling was Rs. 14-11-0, Rs. 7-1-9, and Rs. 7-15-0 respectively. In Mussoorie no water or lighting rate is levied. Water is provided *gratis* from the public hydrants dispersed throughout the station. A charge of Rs. 2 per thousand gallons is, however, made in cases where the supply is provided through house connections, while electric energy is sold at the rate of 4 annas per B. T. U. (Board of Trade Unit) for lighting, and of one anna for power purposes.

To the east of and adjoining Mussoorie is the Military convalescent dépôt of Landour at an altitude of 7,534 feet.

Preliminary estimate for improving the water-supply and providing for electric light.

From the time Mussoorie was originally occupied up to the year 1894 when the first water-works were constructed, the residents obtained their supply of water from the various springs that are to be found usually at a level somewhat below that on which the houses are built.

With the increasing popularity of the station as a health resort, however, these sources of supply proved inadequate and in the year 1900 the question of providing for a further supply was taken up at the instance of the Local Government. Detailed investigations were made by the Sanitary Engineer and in October 1902 he presented a preliminary report and estimate for improving the Mussoorie and Landour water-supply together with a scheme for lighting both places by electric light.

Selection of the Kimpti Falls for derivation of power.

By this scheme the requisite electric power was to be derived from the Kimpti Falls, five miles below Mussoorie to the north-west, and utilised for driving the pumps for the water supply of Mussoorie and Landour as well as for lighting the streets, public institutions, hotels, and private houses in the former station. The cost was roughly estimated at Rs. 6,50,000 while the annual charges, including working expenses, interest, and sinking fund, were put at Rs. 62,000. Against this was assumed an income of Rs. 44,500 from the sale of electric light and water, &c., thus leaving some Rs. 17,500 to be raised by additional taxation. To cover this deficit a water rate of 5 per cent. was proposed to be levied till such time as the profits on the sale of electric current increased.

Substitution of the Bhatta for the Kimpti Falls.

A detailed scheme was then worked out and approved but unfortunately the negotiations entered into for the use of the Kimpti Falls, situated in the Tehri State, fell through and recourse was had to the Bhatta Falls on the south face of the Mussoorie ridge. The measurements taken showed the discharge of this stream to be in excess of that of the one at Kimpti and it had the additional advantage of being situated in British territory and nearer the rail-head at Dehra Dun. This change necessitated some modification of the scheme as originally devised and the final estimates were sanctioned in March 1905 at a cost of Rs. 7,29,560. The Landour part of the scheme costing Rs. 29,000 was subsequently dropped owing to the withdrawal of the Cantonment authorities from participation in it after the estimates had been finally passed. The lines on which the general plan of the scheme was laid are explained in the next chapter.

Mussoorie estimate further recast.

As work progressed and as a result of the inspections made by experts of the whole project, it was found necessary, with a view to ensuring the adequacy of the scheme, to introduce into it some further important reforms. Accordingly in 1908 a further revised estimate was prepared for Rs. 9,72,000. Details of the expenditure incurred against this estimate are given in Appendix A.

Financial.

As has been noticed, the preliminary estimate prepared in 1902 for Mussoorie-cum-Landour was roughly put at Rs. 6,50,000. Then came the substitution of the Bhatta for the Kimpti Falls as the source from which the requisite power was to be obtained, and the necessity for a revised estimate which was sanctioned in 1905 at Rs. 7,29,560.

After a lapse of three years the scheme was subjected to further modification and the estimate for Mussoorie alone reached the figure of Rs. 9,72,000. This is apart from a sum of Rs. 27,000 paid by the Board as interest out of capital for the work that had already been executed. Expenditure to the extent of Rs. 67,000 incurred in repairing the power pipe line that had been breached by the floods of 1909 and in rebuilding the Convent transformer station which had collapsed in the same year, has also to be added to the capital cost, but towards this sum a grant-in-aid of half a lakh of rupees was sanctioned by the Government.

The capital account therefore stands at Rs. 10,16,000 thus :—

	Rs.
Revised estimate of 1908	9,72,000
Interest paid out of capital in 1907 ...	27,000
Repairs to pipe line and transformer station ...	67,000
Total ...	10,66,000
Deduct Rs. 50,000 as the Government grant-in-aid	50,000
Total ...	10,16,000

In addition to this sum of Rs. 10,16,000 the following loans have been raised up to date to put the scheme on a thoroughly satisfactory basis :—

	Rs.
(i) Remodelling the high tension lines ...	35,000
(ii) Motor and pump at the John Mackinnon springs	7,000
(iii) Remodelling the low tension lines ...	70,000
Total ...	1,12,000

These loans have been taken from the Local Government at 4 per cent. and are repayable in twenty years. The total capital cost of the scheme may therefore be taken at Rs. 11,28,000.

Thus the net result is an excess of some Rs. 4,00,000 over the estimate of 1905, which included the Landour scheme and Rs. 1,56,000 over and above that sanctioned in 1908 for Mussoorie alone.

These excesses may be attributed chiefly to the inadequacy of the original estimate. Many items were found to have been under-rated while the charges on account of the constructional staff, amounting approximately to Rs. 60,000, were wholly omitted. There was further an unforeseen liability of some Rs. 36,000 under the head "salaries" owing to the contractor's engineers having to be retained beyond the period estimated as sufficient for the erection of the electrical machinery. Excesses, aggregating Rs. 1,10,750, occurred as noted below:—

	Rs.
(1) Rise in the price of copper	28,850
(2) Extra apparatus, such as lamp standards ...	4,393
(3) Construction of additional reservoirs at Vincent's Hill and at the head works at Bhatta	26,817
(4) Compensation for additional trees and land taken up	21,000
(5) Heavy foundation work for the power house	12,690
(6) Repairs due to wash out on the pipe line ...	17,000

Owing to the first cost of the scheme having been exceeded to the extent mentioned above the annual charges to be defrayed in maintaining it have been raised to a figure substantially larger than was anticipated when it was first mooted. As has been shown, the original forecast of these charges amounted to Rs. 62,000, viz., working expenses Rs. 24,000 and interest and sinking fund, Rs. 38,000.

For a scheme costing Rs. 11,28,000, however, the annual instalment required to meet interest at 4 per cent. and pay off this amount in the periods agreed upon comes to Rs. 67,620 while some Rs. 50,000 may be estimated as being required for "establishment" and "maintenance."

Assuming then that these latter charges will remain fairly constant, the total annual expenditure to be incurred on the working of the scheme amounts to Rs. 1,17,620 or Rs. 55,620 in excess of the original forecast.

The question of income that is likely to be derived from the scheme will now be dealt with, as also the position of the Municipal Board after defraying the cost of its new public water and lighting services as compared with its position in 1908, the last year in which the old lighting and water service obtained.

The building up of a large clientèle for private light and water supplies has developed rapidly as a result of the "House Connection Loan Scheme." Under it the Board make the requisite advances to landlords for installing light and water in their houses and the amounts are recovered in ten yearly instalments without interest.

For this purpose a sum of Rs. 80,000 was borrowed from the Government, viz. Rs. 50,000 for house wiring and Rs. 30,000 for water connections. Apart from this scheme the wiring of small premises has been undertaken for cash payments. The number of houses (including hotels) connected for water up to the end of 1911-1912 was 139 and for light 327. This latter figure includes 133 bazar shops which were lighted on the contract system. A second house wiring loan of Rs. 23,000 was obtained in March 1911.

The gross income derived in the year 1911-1912 from the sale of current, water, meter rents, &c., amounted to Rs. 28,285 but against this had to be set off certain deductions amounting to Rs. 10,324 on account of repayment of interest and capital on the loans aggregating Rs. 1,03,000 referred to above.

In 1908-1909, the last year of working under the old scheme, the profits and loss on the water and lighting services stood as follows:—

Items.	Expenditure.	Items.	Income.	Net cost of municipal lighting and water-supply.
	Rs.			Rs.
Maintenance ...	20,542	Receipts from sale of water		
Sinking fund on old water works loan of Rs. 36,000 ...	2,808	Receipts from sale of light	Nil	29,496
Public lighting ...	6,146	Meter rents ...		
Total ...	29,496		...	29,496

while the balance sheet for 1911-1912 was—

Items.	Expenditure.	Items.	Income.	Net cost of municipal light and water supply.
	Rs.		Rs.	Rs.
Maintenance and establishment ...	52,040	Sale of water ...	7,524	
Sinking fund charges on loan of Rs. 9,72,000	55,926	Sale of current ...	19,444	
Sinking fund charges in house wiring loan of Rs. 50,000 ...	6,165	Rent of electric meters ...	835	
Sinking fund charges on old water-works loan of Rs. 36,000 ...	2,808	Rent of water meters ...	482	
Sinking fund charges on loan of Rs. 30,000 for house connection for water	3,699	Repayment by landlords of instalments of capital cost of installation effected under house wiring loans ...	7,510	85,247
Sinking fund charges on loan of Rs. 44,000 for hydro-electric scheme construction ...	1,760*	Repayment by landlords of instalments of capital cost of installation for water from loans ...	1,816	
Sinking fund charges on loan of Rs. 23,000 for 2nd house wiring ...	460*	...	...	
Total ...	1,22,858		37,611	85,247

* Interest only.

The increased cost of the new scheme to the municipality was thus Rs. 85,247 less Rs. 29,496 or Rs. 55,751.

There is, however, every reason to hope that this increase will be reduced in the near future, for the receipts derived from the sale of light and water will steadily rise as a result of the additional connections now being arranged for.

There is further on the tapis a proposal that the Board should supply the adjoining Cantonment of Landour with water. The latest estimate framed by the Military authorities provides for the supply of 6,000 gallons per day for 90 days during the "season" to supplement the existing Cantonment supply and will result in an income of Rs. 1,350.

Proposals are also under consideration for the supply of current for public road lighting at Landour and for power for pumping the water-supply in the Cantonment up to the top of the hill.

In ten years' time when the house wiring and water connection loans are finally paid off there will be a further increase in the income from the scheme. But over and above this and the further income accruing from the natural increase in the amount of light and water consumed, another important source of revenue will probably arise in the near future. It cannot be long before Mussoorie is connected with Rajpur or Dehra by some mechanical means of transit, and the obvious motive power for such a scheme would be electricity and the obvious source of supply the Municipal Hydro-Electric Station. There is, moreover, the possibility of a paying electrical scheme being worked out before long for the Dehra Dun Municipal Board which will take its power from these works.

With a heavy day load and with practically every house in the station and bazar connected up for water and light with the municipal mains, a forecast of an income of Rs. 60,000 from the scheme is not extravagant and gives the following result :—

Items.	Expenditure.	Income.	Net charge on the rates.
	Rs.	Rs.	Rs.
Interest and sinking fund on capital expenditure of Rs. 11,28,000.	67,620	60,000	57,620
Maintenance and establishment charges	50,000		
Total ...	1,17,620	60,000	57,620

Against this charge of Rs. 57,620 on the rates should be credited the value of the water supplied through public stand-posts and of the current supplied for public road lighting. During the year 1911-12 25,500,000 gallons of water were supplied through public stand-posts and, at a very moderate estimate, this should increase by 25 per cent within the next ten years when the consumption would be 31,875,000 gallons per annum. The value of this at Re. 1 per 1,000 gallons (as against Rs. 2, the price paid for water supplied through house connections) amounts to Rs. 31,875. In the same year (1911-1912) the consumption of current in road lighting was 146,000 B. T. U. Current for lighting in private houses is, as already mentioned, charged for at 4 annas per unit, but taking 3 annas as the rate for municipal road lighting the value of the current consumed amounts to Rs. 27,000. This does not, however, allow for expansion during the next ten years. The value of water and current utilized for municipal purposes may therefore be taken as Rs. 58,875 at the very moderate rates on which the estimate is based, against the annual charge of Rs. 57,620.

When the entire capital cost of the scheme has been paid off, the Hydro-Electric scheme will be a most valuable asset. After the cost of repairs and renewals and the cost of actual maintenance have been defrayed, there will be a handsome surplus resulting probably in reduction of the rates.

The satisfactory accomplishment of the work is due in a great measure to the keen interest taken in the scheme by Mr. G. R. Dampier,

I. C. S., Superintendent of Dehra Dun, who was confronted throughout by serious financial and administrative difficulties and eventually succeeded in raising the funds required for the completion of the work and bringing the scheme to a successful issue. The Engineers to whom credit is chiefly due are Mr. Menzies, Municipal Electrical Engineer, Captain Anderson, Municipal Civil Engineer, and Messrs. Pitkeathly and Rennie, assistants of the contractors for the Power Station and Pumping machinery, who, in addition to their legitimate duties of erecting the power plant, gave valuable assistance to the Municipal Board in the erection of high tension lines, transformer stations, and the power pipe line. Mr. W. Bell, the present Municipal Engineer, also deserves credit for his successful management of the work since its completion and the several improvements he has introduced since he has been in charge. The notes from which the parts of this report referring to electrical work has been prepared were originally written by Mr. Menzies and have been revised later by Mr. Bell. To Captain Anderson, Municipal Engineer and Secretary, we are indebted for the notes from which chapters II and IV have been compiled.

It will be observed that this report deals very fully with the practical defects which have come to light in the working of the scheme and the remedies which have been applied to put it on a thoroughly sound working basis. Many of these defects being of a trivial nature would not have been noticed ordinarily in a completion report but as hydro-electric schemes are at present in their infancy in the Upper Provinces it was considered advisable to bring every little mistake to notice with a view to warn future designers of such schemes against the pitfalls to be avoided.

CHAPTER II.

CIVIL ENGINEERING WORKS.

Head works.

At the bottom of the valley, lying between Vincent's Hill and Barlowganj and midway between the villages of Bhatta and Kiarkuli, flows a small perennial stream, which, issuing from the southern slopes of the valley in the shape of several small springs, is a combined current at these villages and forms what is called the Bhatta or Kiarkuli *nadi*. The water power of this stream is utilized to drive the Pelton wheels which form, one might say, the main spring of the Mussoorie Hydro-Electric Scheme. The minimum discharge of the stream during the dry season is $8\frac{1}{2}$ cubic feet per second.

The offtake of the supply flume is situated just below the junction with the main stream of a small tributary *nala* which takes its rise a little to the west of the Kiarkuli village.

This site was selected partly in order to include the water of this tributary which amounts at its minimum to $1\frac{1}{2}$ cusecs, and partly because at that point the bed of the stream passed through a rocky formation of limestone and conglomerate, which ensured a good foundation for the dam.

The drainage area of the valley above the dam is about two square miles, and the average slope of the ground within this area is roughly 1 in 2.

The head works comprise, (*a*) the dam and intake, (*b*) the reservoir and offtake, and (*c*) buildings for housing the men in charge. See plates nos. II, III, and IV.

The dam has a clear crest length of 75 feet. The height of the crest is 7 feet above the lowest point of the bed. The foundations are carried 2 feet into solid rock at the lowest point of the stream and stepped up towards each bank. The section of the dam was designed strong enough to admit of its being raised 3 feet above present level if such a step were ever found necessary to supplement the storage capacity of the reservoir. After the first rains, however, it was found that the hollow on the up-stream side of the dam had silted up to the crest level, and from the amount of detritus brought down during floods it was quite clear that this would happen to whatever height the crest of the dam might be raised.

Owing to the immense quantities of boulders and other *debris* which pass over the dam during the rains, there has been in the last two years considerable abrasion, both on the crest of the dam and on its down-stream face, which has a batter of 4 in 7. The stone used (dolomite) is the hardest procurable locally, but something more unyielding is needed to be proof against the action of this flint-laden torrent when in full flood. Repairs to the crest can be done fairly easily, but the down-stream face is difficult to keep in repair. It would seem therefore that it would have been preferable to have designed the dam with a vertical face on the down-stream side so as to enable the *débris*-carrying water to fall clear of the masonry.

The intake consists of two channels, 3 feet wide, divided by a masonry wall. The sill of the intake is 2 feet below the crest level of the weir. The supply is regulated by means of planks working in grooves and sluices. The sluices are raised and lowered by a worm gear. The planks admit only the clear surface water. This arrangement did not answer very well by itself the first year, and a considerable amount of detritus accumulated at the mouth of the flume. A masonry wall has now been built across the mouth of the intake with an opening protected by an iron grill composed of $\frac{5}{8}$-inch rods spaced $\frac{3}{8}$ of an inch apart. This arrangement has now been in force two rainy seasons and has acted admirably.

The size of the reservoir was practically determined by the available space between the hill-side and the stream. It is 163 feet 6 inches long, and its breadth varies from 45 feet 6 inches at the lower, to 27 feet 9 inches at the upper, end. Its depth at full supply is 9 feet 6 inches and its storage capacity is 38,000 cubic feet after allowing for 1 foot of *débris* on an average over the floor.

An overflow for waste water, 40 feet long and 6 inches deep, has been provided in the outer wall of the upper section, and there are three scouring pipes of 8 inches diameter at floor level. It is absolutely necessary to prevent twigs, leaves, sand, and grit of any kind from entering the penstock chambers. The importance of this will be readily understood when it is noted that the nozzles, which direct the water to the vanes of the Pelton wheels, are only 2 inches in diameter while the velocity with which the water strikes the vanes is about 100 feet a second. The length and breadth of the reservoir reduces the velocity of water passing through it considerably and it acts as a settling tank in itself. The water from it is drawn off at its lower end over regulating planks, the surface water only being allowed to pass into the penstock chambers. These precautions insure the settlement of the heavier matter held in suspension while all floating matter is intercepted by strainers attached to the penstock chambers themselves. These strainers consist of flat iron bars (1 inch × $\frac{1}{4}$ inch) placed edgewise $\frac{1}{4}$ of an inch apart.

The necessity for a reservoir was not recognized until April 1908 when the work on the Hydro-Electric Scheme was well in hand, and it was still incomplete when, in April 1909, the pumps were first set in motion. As a temporary arrangement a channel 5 feet wide was made on the floor of the reservoir to convey the water to the penstock chambers. The channel proved such a success in the dry season when the water was clear that it has been retained for use when the reservoir is being cleaned. By means of this expedient it is possible to keep the whole plant running much longer and to reduce the time of closure to an hour or two, i.e. while the channel itself is being cleaned. When the channel is being used the 12-inch pipe in the outer wall of the reservoir is kept open and the supply of water is regulated so that it does not overflow into the reservoir itself. It is found that the deposit of silt in the reservoir is small. At the end of 1910, after it had been in continuous use for nine months, the depth of silt was $1\frac{1}{2}$ feet at the upper end and 10 inches at the lower and the greater part of this was deposited in the rainy season.

The dam, intake, reservoir, and penstock chambers are all built of coursed rubble masonry of the best and hardest dolomite procurable, laid in mortar composed of equal parts of *kankar* lime and coarse river sand or *bajri* The face work is squared.

The up-stream faces of the dam, and the interior faces and floors of the flume, reservoir, and penstock chambers, are plastered with a mixture of one part Portland cement, 3 parts *kankar* lime, and 3 parts coarse river sand. The surface is rendered with neat Portland cement. All other exposed surfaces have been pointed with a mixture similar to that used in the plaster work.

Stone ballast was used in all concrete work.

Power pipe line.

The total fall in the power pipe line (plate no. V) is 992 feet. The working head varies between 996 and 999 feet and the static pressure between 430 and 433 lbs. per square inch, according to the level of the water in the reservoir.

The mean velocity of water in the pipes is 3 feet per second in the 12-inch section when two wheels are working at their ordinary speed. The head consumed by friction is about 25 feet. The pipe line consists of two parallel lines of mild steel pipes placed 4 feet apart centre to centre. The pipes are of mild steel, lapwelded, and vary in thickness from $\frac{3}{16}$ of an inch at the upper end to $\frac{3}{8}$ of an inch at the lower and according to the static pressure. The total length of the pipe line is 4,354 feet in three sections of different diameters. The upper section is 1,253 feet long and consists of two pipes of 16 inches internal diameter each. The pipes in this length are joined together by what is known as the "Albion" joint, the details of which are shown in plate no. VI, figure 1. The ends of the pipes are turned up to form a flange and the joint is made by drawing the flanges together by means of cast steel loose flanges encircling the pipes.

The middle section is 1,556 feet long and consists of two pipes each of 14 inches internal diameter and the lower section is 1,545 feet long with pipes of 12 inches internal diameter. In both these lower sections the cast steel flanges are screwed on to the pipes, the ends of which are expanded into them by cold hammering. The screw threads have a taper of $\frac{1}{16}$ of an inch in 1 inch to ensure tight fitting of the flanges.

The flanges are joined together with corrugated brass joint rings smeared with manganesite jointing paste. The details of this joint are given in plate no. VI, figure 2.

The receiver is shown in detail in plate no. VII. Its total length is 69 feet 9 inches and it consists of a Y piece, the branches of which are each 12 inches in diameter and the stem 21 inches. This Y piece combines into one the double pipe line. The stem of the Y piece consists of three lengths of 21 inches, 15 inches, and 12 inches in diameter, from each of which takes off a 12-inch pipe leading to the Pelton wheels.

An extra T piece has been provided (with a blank flange) near the Y piece from which a branch pipe can be taken off to a fourth Pelton wheel should it ever be required. All the sections of the receiver are of welded steel plates varying from $\frac{3}{8}$ of an inch to $\frac{9}{16}$ of an inch in thickness and the joints are the same as those described for the middle and lower sections of the power pipe line.

In order to prevent expansion across the Pelton wheels, the middle pipe of the receiver is provided with three "welded on" flanges and is embedded in a massive "thrust block" of cement concrete. This precaution was taken in order to prevent any movement due to expansion or contraction which might affect the connections with the Pelton wheels.

A relief valve is attached to the receiver on a 6-inch branch pipe. The object of this valve is to protect the pipes from shock due to "water-hammer" when the valves are closed too suddenly or when the nozzles get accidentally choked with foreign matter. It discharges into a masonry pit below ground level, which in turn is connected by means of a masonry channel, with one of the tail races under the power house (plate no. XI).

Three "wash-out" or drain pipes are provided [marked (*a*), (*b*), and (*c*) on plate no. VII] one in each of the pipes immediately above the receiver and one in the receiver itself. They are 4 inches in diameter and all three merge into one in the "drain valve" pit [marked (*d*) on plate no. VII] from which the water passes into the river below. Immediately above the Y piece there is an air valve on each pipe line and also a sluice valve which admits of either line being in service whilst the other is emptied for repairs. Each of the branch pipes from the receiver to the Pelton wheels has a sluice valve outside the power house and another with two byepass valves inside, immediately behind the nozzles. By means of the valve outside the water can be shut off when repairs are necessary to any of the valves inside the power house. When starting up a Pelton wheel the byepass valves which are 2½ inches in diameter are first opened. This reduces the pressure on the main valve which has a diameter of 12 inches and renders it easier to work.

The pipe line was originally designed and laid as an "above-ground line" throughout its entire length with a view to facilitate inspection, the detection of leaky joints, and their repairs. As the pipes were thus exposed to very large variations of temperature, particularly when empty, it was necessary to make careful provision against contraction and expansion. Any tendency in the pipes to creep down hill was intensified by the steep gradients prevailing along the greater part of the line. The distribution of thrust blocks and expansion joints along the line is shown on the working plate no. XII. In the lowest section (B) the thrust block on the receiver referred to above prevents expansion in the direction of the power house. Expansion on this section and thrust from section C are taken up by the combined expansion joint and thrust block no. 23. Expansion joint and thrust block no. 49 takes up the expansion in section C and the thrust from section D, the expansion on which is taken up by two bends there being a thrust block at both ends of this section. Thrust block no. 100 takes the thrust in section E whilst the expansion is taken by expansion joint no. 153. Similarly the thrust and expansion on sections F, G, and H aret aken up by the expansion joints and thrust blocks nos. 153, 193, 238, and 265. It will be observed that in section D there is a thrust block both at the upper (no. 100) and lower (no. 49) ends, the expansion in this case being taken up by the two intermediate bends. An expansion joint (no. 265) is also provided at the pipe head to take the expansion on section H of the line and thus protect from injury the end walls of the penstock chambers into which the pipe heads are built. Details of a combined thrust and expansion joint are given in plate no. VI. The thrust blocks are securely anchored by four holding down bolts, 5 feet long and $1\frac{1}{2}$ inches in diameter, set in massive blocks of cement concrete. The arrangements for expansion and contraction worked admirably during the first hot weather that the pipe line was in use (1909), but during the rains, which in that year were abnormally heavy, slips occurred at various parts of the line and a number of the pipes were badly damaged by fragments of rocks and boulders from the hillsides above. The experience of this rainy season plainly indicated the necessity for covering up the pipes wherever the line was carried along a steep hillside, and this was accordingly done before the rains of 1910, with the result that not a single pipe was damaged, though the rains were practically as severe as those of the previous year. The method adopted for covering the pipes from the head works to expansion joint no. 153 above the upper crossing of the stream is shown in plate no. V, figure 1. The covering material is laid with a sharp slope across the direction of the pipe line so that rocks and stones rolling down from above shoot over the line and rarely disturb the dry stone pitching to any appreciable extent. From no. 153 to no. 100 the pipes have been left uncovered as the slope of the hillside runs parallel to the pipe line and there is practically no risk of damage to the pipes. Wherever the hillsides are composed of soft material the pipes have been covered with shale and earth to a depth of from 2 to 3 feet except where the pipes are raised well above ground on masonry pillars and are practically safe from rolling stones.

The width of the pipe track is 8 feet. The pipes are laid on *sal* sleepers 8 feet × 8 inches × 5 inches spaced $4\frac{1}{2}$ to 6 feet apart as it was intended at first to keep the line above ground the whole way.

The nature of the hillsides along the pipe line varies from hard rock in some places to soft shale in others.

From chainage 2,703 to 2,974 the main stream is crossed (plate no. VIII). As originally constructed the pipe line was carried over the stream on a bridge. This was destroyed by an abnormally high flood on the 11th August 1909. It had a clear span of 40 feet and consisted of masonry abutments and wingwalls with a superstructure composed of two trussed rolled steel beams 12 inches × 5 inches in section, placed 4 feet apart. The rolled beams were braced together laterally by iron tierods and *sal* sleepers 9 inches × 6 inches spaced $4\frac{1}{2}$ feet apart. The pipes were laid on the sleepers, vertically over the rolled steel beams and a planked gangway was provided for inspection purposes. The bed of the stream is here composed of fairly hard shale which, at the time the bridge was built, cropped out above the surface only on the left bank, being elsewhere overlaid by huge detached masses of limestone, rock, and conglomerate which to all appearances had withstood floods unmoved for generations. The foundations of the left abutment were let into the shale, whilst the right abutment was on detached rocks built in with masonry and concrete laid in *kankar* lime. The waterway of the bridge was about 450 square feet, whilst the drainage area above the bridge was approximately 2¼ square miles. Owing to a sharp bend in the stream the set of the current was towards the right bank where the pipe line crossed the bridge with an upward gradient of about 1 in 8. The flood topped the right bank and rose 3 feet higher on this side than on the left abutment and scoured it out for a width of 40 feet behind the right abutment which, together with the wingwalls, was entirely swept away. The left abutment was uninjured, except the upstream wingwall which was destroyed by a spill from a tributary *nala* which broke through behind and above the bridge.

The main stream is again crossed at chainage 3,975 (plate no. VIII). The bridge at this crossing was similar in design to the upper bridge but crossed the stream on the level. It had a span of 43 feet and 425 square feet of waterway. The drainage area above the bridge was 2½ square miles. From the left abutment a revetment wall was constructed along the left bank of the stream to a little beyond the down-stream end of the power house, a distance of 250 feet. At the bridge site the right bank is composed of hard shale rock which dips down abruptly in the middle of the bed and reappears on the left bank, the intermediate portion being composed of the usual conglomeration of boulders and shingle overlaying the rock. The flood topped the pipe line by 2¾ feet on the right bank and by 6 inches on the left bank, on which side also the floor of the power house was submerged to a depth of several inches. The bridge itself was totally destroyed, only portions of the foundations of the abutments being left, whilst the left bank revetment wall was washed out for a distance of 100 feet below the bridge.

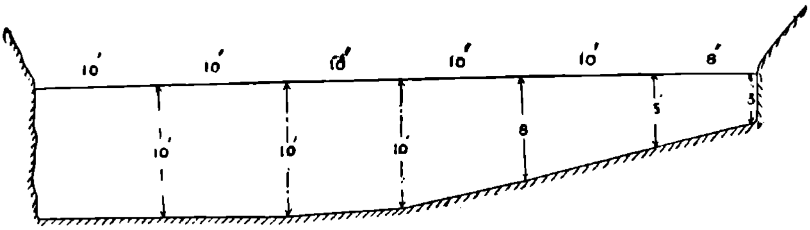
The rainfall actually registered at Mussoorie on the night of the 11th August 1909 when the bridges gave way amounted to 9 inches in about three hours. It is quite probable, however, that this was considerably exceeded in the lower half of the drainage area, as it is a well established fact that the average rainfall is less at Mussoorie than it is on the lower slopes of the hills towards Rajpur.

Flood sections of the stream were taken at various points at and below the two crossings immediately after the flood occurred and the following results were obtained :—

(1)	At the upper crossing	1,334	square feet flood area.
(2)	At the lower crossing	1,458	" "
(3)	At 200 feet below the lower crossing ...	903	" "
(4)	At 500 feet below the lower crossing ...	487	" "

Nos. (1), (2), and (3) give an entirely erroneous idea of the flood section owing to the extent to which scour occurred at the points where they were taken, whilst no. (4) is considered to represent fairly the actual area of the flood, since it was taken on a fairly straight stretch of the stream where it flows through a narrow gorge 50 to 60 feet wide with cliffs on each side and where there had been little or no alteration in the bed or banks during the flood. The mean slope of the bed of the stream taken on measured lengths of 1,000 feet was found to be 1 in 6·61 at the upper crossing and 1 in 7·52 at the lower crossing. The flood discharge at 500 feet below the lower crossing is calculated by Kutter's formula to have been 6,569 cusecs.

Flood section at 500 feet below lower crossing.



Area of flood section A=487 sq. ft.

Wetted perimeter =71·89. ft.

Hydraulic mean depth r=6·77

Slope of bed $S=\frac{7\cdot52}{1000}$

N=Co-efficient of rugosity=0·035 for very rough channels.

$$Q=\left\{\frac{\frac{1\cdot811}{N}+41\cdot6+\frac{0\cdot00281}{S}}{1+\left(41\cdot6+\frac{0\cdot00281}{S}\right)\frac{N}{\sqrt{r}}}\right\}A.\sqrt{r.s.}$$

$$\left\{\frac{\frac{1\cdot811}{0\cdot035}+41\cdot6+\frac{0\cdot00281}{\frac{7\cdot52}{1000}}}{1+\left(41\cdot6+\frac{0\cdot00281}{\frac{7\cdot52}{1000}}\right)\times\frac{0\cdot035}{\sqrt{6\cdot77}}}\right\}\times487\times\sqrt{\frac{6\cdot77\times7\cdot52}{1000}}$$

=6,569 cusecs.

The drainage area above this flood section is approximately $2\frac{1}{2}$ square miles and the discharge is equivalent to an average rainfall over the whole drainage area of 4·07* inches an hour.

$\frac{569\times60\times60\times12}{2\frac{1}{2}\times5280\times5280}$.

After the flood of August 1909 the first thing to be done was to repair temporarily the break in the pipe line at both crossings to enable the plant at the power station to be re-started. Twenty-five pipes were carried away by the flood some of which were never found, whilst those that were recovered were mostly so bent, twisted, and battered that they had to be scrapped. It was therefore necessary, as there were only a few spares in hand, to break up a portion of one of the lines in order to obtain pipes to complete at least a single temporary line at the crossings. This was successfully accomplished within a fortnight of the occurrence of the flood. The pipes were supported on trestles made of rough *sal* beams erected under each pipe joint. This temporary expedient answered its purpose till the beginning of June 1910. The question of safeguarding the pipe line against floods at the crossings was carefully investigated on the spot in September 1910, by a committee of Engineers. The following proposals were fully discussed and considered :—

(1). To carry the pipe line under the bed of the stream at both crossings.

(2). To carry it over on suspension bridges of ample span and at as high a level as practicable above the bed.

(3). To avoid the crossings altogether by carrying the pipe line along the left bank from above the upper crossing to the power house.

The majority of the Committee were in favour of the first proposal. This was also approved by the Chief Engineer to Government, who made a personal inspection of the ground in November, and it was finally adopted. The principal objection to the second proposal was the difficulty in obtaining secure foundations for the piers of the bridges. The third proposal was rejected partly on the score of cost, but mainly because, owing to the nature of the ground (a steep glacis of the *débris* surmounted by a high cliff) the pipe line would have had to be carried for a distance of about 300 yards on the top of a heavy revetment wall built up from the bed of the stream on a foundation always liable to be scoured out by floods. The risk to which such a revetment wall would have been exposed will be readily understood from the fact that the average fall in the bed between the upper and lower crossings is about 1 in 4 whilst the bed itself is a mass of boulders and large detached masses of rocks, changing and shifting with every flood. It was absolutely necessary that the pipe-laying in the bed of the stream should be completed before the rains set in; but it was hopeless to expect delivery of the necessary pipes and bends from England. Under these circumstances it was decided to utilize a further portion of the line which had been thrown out of use for the crossings. At the same time a sufficient number of pipes were ordered from England. This work involved the bending of a considerable number of pipes on the spot as well as the cutting and screwing of special lengths.

The method employed in bending the pipes was simple and effective and therefore deserves description. The pipe was first laid in a horizontal position. One end was then clamped down by two iron collars and four holding down bolts to a block of concrete sunk about 5 feet in the ground. Close to this block and under the pipe was an open fire hearth about 2 feet deep. At the other end of the pipe a set of shear legs with a differential pulley block was erected over a concrete platform level with the platform at the other end of the pipe. Wood fuel cut into thin small pieces was then piled up all round the part of the pipe to be bent and a brisk fire kept up till a dull red heat was obtained. The bending was then done by very gradually raising the loose end of the pipe by means of the differential block until the required angle with the horizontal was obtained. This was measured from the calculated vertical height above the platform at the end of the pipe. The pipes which were 12 inches in bore and $\frac{3}{8}$ of an inch thick were in this way successfully bent to a maximum angle of 23°20′ from the straight.

The original alignment of the pipe line was adhered to at the lower crossing, but was slightly altered at the upper, where it was moved 12 feet into the hillside on the right bank with the object of protecting the pipes as far as practicable from the erosion caused by the set of the stream on that side.

Details of the work done at the crossings are given in plate no. VIII.

The pipe trench was excavated 8 feet wide and 10 feet deep at the lowest point of the bed. The excavation was almost entirely done by means of a magneto exploder with blasting gelatine; the material to be dealt with being compact shale and large boulders. In breaking up large boulders the best results were obtained by using a single gelatine cartridge with water tamping. When the bore hole was properly placed, this generally split the boulder into a number of pieces without scattering the fragments. The stream during construction was carried over the trenches in shoots 6 feet wide and 1 foot deep, made of *chir* planking. In order to reduce percolation into the trenches as far as possible the upper ends of the shoots were placed some little distance above the crossings at places where compact shale cropped out and rendered the bed impervious to water. On the downstream side of the trenches the shoots had to be carried to points where the bed level was lower than the bottom of the trenches. At the upper crossing, the cutting being almost entirely in hard shale, no difficulty was experienced in keeping the trench free of water and a 3-inch bilge pump worked by hand was found sufficient for this purpose. At the lower crossing, however, the bed being of more porous material a 3-inch and a 4-inch bilge hand pump had to be kept going night and day.

The trench filling (plate no. VIII, figure 1) up to 1 foot above the tops of the pipes was laid in concrete composed of 100 parts by measurement of stone ballast broken to 1½-inch gauge, 12 parts Portland cement and 24 parts coarse river sand. The same material was used for a width of 2 feet on the down-stream face of the trench up to the stone flooring which was made of squared and dressed (locally quarried) stone laid in mortar composed of one part cement and two parts river sand and flush pointed with pure cement. The remainder of the trench filling below floor level was done with concrete composed of 100 parts stone ballast, 18 parts *kankar* lime and 18 parts river sand. The portion of the trench above the floors was filled in and dressed off to the bed line with boulders, shingle and *bajri*. At the upper crossing a wall was built across the trench on the right bank to guard against the stream breaking through at this point during floods, whilst at the lower crossing the flooring and concrete terminated at the new retaining wall constructed along the left bank to replace the one destroyed by the flood of 1909.

Since the alteration carried out in 1909-10 the power pipe line has caused no serious trouble but experience has shown that it would have been better to have run the pipes to the power house by different routes. Had this been done there would have been much less danger of a landslip carrying away both pipes at the same time. Another point which is open to criticism is the merging of both lines into one at the Y piece; it would have been better to continue the pipes right on. As matters stand at present in the event of a breakdown to either of the main sluice valves above the Y piece the plant must be shut down to effect repairs. When the plant had been in operation for a few months it was discovered that there was a rather heavy deposit of scale forming on the inside of the pipes and it was feared that if this went on increasing serious trouble would be experienced. Fortunately this has not happened. During the annual overhauling of the pipe line valves it was found that there was no increase in the deposit in the pipes between the years 1911 and 1912 and what deposit there was, was very soft and quite easy to remove. The only trouble experienced with this deposit is that it silts up in the sluice valve seats and prevents the sluice from getting home. Trouble has been experienced with the byepass valves. These were made of cast steel and every one of the six byepass valves in the engine room has had to be changed due to holes developing in the valve seat bottoms. The brass byepass valves on the main valves outside the power house have given no trouble at all, which proves that brass for this size of valve is the most satisfactory.

The generating station (plate no. IX) is situated on the left bank of the Bhatta stream about $7\frac{1}{2}$ miles by road from Mussoorie and is connected with the Rajpur-Mussoorie cart-road by a service road $2\frac{1}{8}$ miles long and 10 feet wide, having a gradient of 1 in 10. Power station.

The station comprises the following buildings :—

(1) Power house.

(2) Workshops.

(3) Superintendent's quarters.

(4) Quarters for the native subordinate staff.

The power house (plates nos. X and XI), which contains three sets of Pelton wheels and generators, measures 70 feet × 30 feet inside and has an annexe measuring 22 feet × 10 feet for the accommodation of the switch board apparatus, &c. As regards material and workmanship the power house is of the type usually adopted for the better class of public buildings in the Dehra Dun district, being constructed of a combination of rubble masonry and brickwork, laid in mortar, composed of 1 part stone lime and 2 parts river sand. Owing to the difficulty of obtaining a good bond with the stone locally procurable, bands of brickwork are given in this class of work at intervals of about 3 feet in the height of the walls, whilst the jambs of the doors, windows, and other openings, as well as all arch work, are also constructed of brickwork.

The roofing is of galvanized corrugated iron 22/B.W.G. laid on purlins of angle steel and supported on mild steel trusses. The flooring is of ordinary terracing finished off with a layer of cement concrete $1\frac{1}{2}$ inches thick. The walls are lime-plastered inside and pointed outside. The doors and windows are of deodar wood hung on frames of mild steel angles.

The foundations for the Pelton wheels and alternators are constructed of Portland cement concrete which is laid and rammed in wooden boxes of the exact size and shape required.

The tail races leading from the Pelton wheels to the stream are constructed of brickwork laid in *kankar* lime with a backing and footing of ordinary concrete in stone lime. The exposed faces of the tail races and of the Pelton wheel chambers are plastered with Portland cement. The relief valve pit and channel are of similar construction to the tail races.

A 5-ton travelling crane runs on rails laid on a brick corbel at a height of 15 feet above floor level.

The workshop (plate no. X) comprises a machine room 30 feet × 20 feet, a smithy 20 feet × 11 feet, and a store room 20 feet × 10 feet, and is of similar construction to the power house. The machine room is furnished with a double-geared surfacing and screw-cutting lathe, a pillar drilling machine, a screwing machine, a hack-saw and a grindstone, all of which are driven by a 5 B. H. P. motor provided with the necessary shafting, pulleys, and reduction gear. The smithy contains two Caledonian hearths with a blowing fan driven by a small 1 B. H. P. Squirrel cage Induction motor.

Transformer stations.

Twelve transformer stations have been constructed at various points on the high tension lines between Barlowganj on the south and Herne Hill on the north, for the distribution of current at low voltage over the areas they are intended to serve. The positions of these stations are indicated on plate no. I. In the original design (plate no. XXV) provision was made for a transformer room 12 feet × 11 feet in which there was ample space for a second transformer if found necessary in the future, and a tower 6 feet × 6 feet (inside measurement) for the apparatus connected with the high and low tension lines. Subsequently, however, these dimensions were reduced on the score of economy (plate no. XXV).

Only one station, viz. that at Dunseverick, was built entirely in accordance with the original design, it having been practically completed before a revised plan was ordered. The station at the Happy Valley (which was also in hand at that time) and the one on the Convent estate were constructed on the original plan except the upper part of the tower which was built according to a revised plan (plate no. XXVI, part 1). Details of the nine stations constructed on the revised plan and as finally remodelled are given on plate no. XXVI, part 2. The accommodation in the revised design was found to be rather cramped, both in the tower and the transformer room, and the inside dimensions given in the original design are considered to be the irreducible minimum permissible for convenient working. Owing to two accidents from electric shock during the first year of working, it was considered necessary to fence in the transformer stations to prevent unauthorized persons from gaining access to the building.

CHAPTER III.

ELECTRICAL INSTALLATION.

SECTION NO. I.—POWER STATION.

THE generating plant consists of three units with an output of 150 kilowatts each. These were supplied according to the specification drawn up by the Municipal Electrical Engineer in 1905.

This specification was as follows:—

1. The number of water motors required is three. They must be of approved design suitable for direct coupling to three-phase alternators, and be complete with all fittings and mountings together with suitable governors as hereinafter specified. **Water motors.**

2. The total head of water is 1,023 feet with a minimum discharge of 7·7 cusecs or 462 cubic feet per minute. This will be conveyed to the motors in two steel pipes 16 inches, 14 inches and 12 inches internal diameter; each diameter of equal length making a total length of 9,860 feet for the two pipes. The pipes will be used either together or singly.

3. The motors to be of 275 B. H. P. each and to work at a normal speed of 500 revolutions per minute. They will be direct coupled to three-phase alternators of 150 kilowatts each with exciters on the same shaft. The extra power is to meet any overload.

4. The maximum load, for the present, is represented by two sets (300 K. W.) and the third forming a stand-by.

5. The motors to be of the enclosed type with casings of steel plates made perfectly water-tight, and provided with suitable glands to prevent leakage along the shaft.

6. The shaft to be of ample strength for the power to be developed, running in extra long bearings with ring lubrication, and to be fitted with half flexible coupling.

7. Each motor to be provided with a steel or cast iron underframe extended on one side to receive the generator.

8. The inlet to each motor to be fitted with an extra heavy sluice valve with flange for connecting to branch of the pipe line.

9. Tenderers must include all necessary fittings, such as pressure gauges, gate valves, entrance tapers, &c., also relief valves capable of maintaining the pressure in the pipe line within limits. A list of these with detailed prices and a complete list of spares should be sent.

10. The commercial efficiency of the motors should be filled in, in the annexed table.

GUARANTEED EFFICIENCIES.

	Full load.	¾ load.	½ load.
Water motors, 275 B. H. P. ...			

1. Each motor to be provided with an automatic, quick-acting sensitive hydraulic governor providing constant speed for all loads, and suitable for a three-phase lighting and power transmission plant working at 50 cycles and at a pressure of 6,600 volts. Special means to be provided to prevent "hunting" or over-running. They should be fitted with an equalising device for automatically dividing the load between two or more generators, and so arranged that the speed regulation of all governors can be effected from one central position on the switch board to simplify **Governors.**

the paralleling of the generators. The governors must be fully described and explained by drawings showing method of fixing, driving, and action of regulation. Tenderers must state the percentage of speed variation in the annexed table :—

	Variation of speed %.	Time taken to return to normal.
1. Instantaneous change from full to no load		
2. 50 % change in the load		
3. 25 % " "		
4. Ordinary gradual change		

Alternators.

1. Alternators to be three in number, each being arranged to stand on the same bed-plate as the water motor driving it, and to be provided with two long bearings of the ring oiling type and extended shaft with half flexible coupling.

2. Each alternator to be capable of an output of 150 kilowatts at an E.M.F. of 6,600 volts at the terminals when running at 500 revolutions per minute. The E.M.F. curves to have as nearly as possible a true sine form. The three currents to differ in phase by 120 degrees.

3. Alternators to work with a periodicity not exceeding 50 complete alternations per second, and they must be so constructed that they will work continuously in parallel with each other at all outputs and under all ordinary conditions.

4. They must be of the revolving field type with stationary armatures. The latter to be slotted with two slots per pole per phase. The windings to be star connected with the neutral point earthed at the power house.

5. The field magnets are to be so wound that the generators will give their maximum output at the correct speed when supplied with an exciting current at an E.M.F. of 110 volts; and the total electrical energy absorbed in exciting the fields of each alternator, when running under full load conditions, must not exceed 4 kilowatts.

6. Alternators to be alike in every respect, and all parts to be strictly interchangeable. Particular attention is to be given in the design of the machines to the accessibility of the various parts for examination, cleaning, ready renewal and repair or adjustment; to the strength and stiffness of the shaft and the mechanical connection of the rotating parts thereto; and, generally, to the mechanical construction and solidity of the whole combination.

7. Conductors to be of high conductivity copper throughout, having a conductivity of not less than 99 per cent. of Mattiesson's standard for pure copper. They must be well insulated and coated with non-conducting varnish unaffected by oil or water. The windings to be spaced equidistantly around the interior circumference.

8. The inherent regulation must not exceed 5 per cent. of normal between no load and the rated full load on non-inductive load under conditions of constant speed and excitation, and not greater than 18 per cent. on an inductive load with a power factor of 0·80.

9. High tension brushes and terminals are to be securely enclosed in boxes with glass sides, or protected in some other approved manner.

10. The insulation of the armature windings must be tested at twice the normal pressure applied between the conductor and the framework. The insulation resistance after a continuous run of 6 hours to be stated.

11. After 10 hours' continuous run on full load the temperature of no part of the alternator measured thermometrically should exceed 70 degrees F. or 40 degrees C. above that of the surrounding air with normal conditions of ventilation.

12. The commercial efficiencies of the alternators should be filled in, in the annexed table.

GUARANTEED EFFICIENCIES—POWER FACTOR=1·0.

	50 % Over load.	Full load.	¾ load	½ load.
Three-phase alternator 150 K. W.				

13. Tenderers must include a complete list of all spare parts to be supplied with each machine with detailed prices.

14. Descriptive plans must be sent with the tender showing full details and dimensions as well as plans of the foundations, &c., required.

15. Each alternator to carry in a conspicuous position a name plate giving output in kilowatts, volts, amperes, revolutions per minute, frequency and full load excitation.

Exciters.

1. Exciters to be three in number, each mounted on the same shaft as the alternator it has to serve. They must be of the same pattern with all parts strictly interchangeable.

2. They are to be compound wound giving an E.M.F. of 110 volts and an output of 4 kilowatts.

3. The brushes to be of carbon, easily accessible for adjustment and renewals. Brush-holders to be provided in duplicate.

4. Each exciter to be provided with shunt resistance having at least 40 contacts, and a suitable regulating resistance in the exciting circuit of the generator must also be furnished.

5. A complete set of spares for each machine should be included in the tender with full details and prices.

Main switch board.

1. The main switch board to consist of seven marble panels, polished in front and bevelled on the edges. The slabs to be at least 2 inches thick, securely fixed into the walls allowing a clear space of at least ten feet between the back of the panels and the wall. The whole to be of approved design, neat and strong.

2. The general arrangement of the switch board to be as follows :—

(a) Three generator panels, each fitted with—

3 Ammeters with transformers, one on each phase.
1 Voltmeter with transformer.
1 Watt-hour meter with transformer.
1 Triple pole high tension switch.
1 Synchronizing socket and plug.
1 Double pole, single throw field switch.
1 Field Rheostat.
1 Exciter Field Rheostat.
1 Exciter ammeter.

(b) One synchronizing panel, fitted with—

A suitable synchronizing device clearly visible from the generator panels and provided with a synchronizing transformer, voltmeter, lamps and phase indicator.

(c) Two feeder panels, each fitted with—

1 Ammeter with transformer.
1 Watt-hour meter with transformer.
1 Triple pole high tension switch with fuses.
3 Lightning arresters with earth-plate.

(d) One station panel, fitted with—

1 Triple pole high tension switch with fuses.
2 „ „ low „ „ „ „ (one for station lighting and one for the workshops).
2 Ammeters reading up to 40 amperes.
1 Voltmeter „ „ „ 450 volts.

3. The bus bars to consist of copper strip of such section that a current density of 800 amperes per square inch is not exceeded. They are to be carried on suitably insulated supports and run the whole length of the board. They must be so arranged that if necessary their section can be increased at a future date. Bus bars to be provided with a voltmeter.

4. The field regulating switches are to be placed in front of the switch board directly opposite the panel of the alternator whose fields they regulate.

5. The whole of the instruments, switches, fuses and terminals must be designed and arranged so as to reduce the risk of contact with high tension metal-work to a minimum and the general design of the board must be such as to render all high tension bare metal-work practically inaccessible under all working conditions. Arrangements to be provided whereby the fittings and the bus bars may be examined and repairs made with ease and safety.

6. Watt-hour meters to be of approved design and make, of non-inductive type. They must register the real energy passing through them when placed on an inductive circuit, and be accurate to within 2½ per cent. over their whole range.

7. All instrument transformers are to be in water-tight cast iron cases, and all connections must be so arranged that the transformers can be readily changed in the event of an accident.

8. One voltmeter to be provided for the exciters with plugs in the panels for connection thereto.

9. The switch board to be surmounted by a pediment with a non-magnetic clock. And each panel to be provided with lamp brackets complete with fittings, &c.

10. Tenderers must include all connecting up of machines and feeders, &c., ready for work.

The above specifications were issued and tenders received from most of the leading electrical contractors. The Board, advised by the Electrical Adviser to Government, accepted the tender of * * * * * * of Edinburgh.

Description of the Plant.

The water motors are of the Pelton type, and were made by * * * * * * of London. These motors although rated as 275 B. H. P. are capable of developing 300 H. P., if required. The wheels are 56 inches in diameter, made of solid wrought steel, turned and truly balanced. The weight of each wheel is approximately 35 cwt. and the speed 500 revolutions per minute. The buckets are made of phosphor bronze and fixed to the disc by means of countersunk headed set screws. The shaft is of mild steel 6⅛ inches in diameter in the body and 5⅜ inches in diameter in the journals, of which there are two, 15 inches long. On one end of the shaft a half coupling is fitted. Plate no. XXVII and shows the general arrangement of the water motor in full detail.

The bearings are of white metal, self-oiling with ring lubrication, fitted in pedestals bolted to the cast iron bed-plate.

The casing is semi-circular, constructed of steel plate and angle iron, and screwed to the bed-plate by means of studs and nuts. A rubber joint is inserted between the casing and the bed-plate. Where the shaft passes through the casing a special gland is fitted to prevent the escape of the water. On the top of the casing a tachometer is fixed. This is driven by means of pulleys and belting from the main shaft.

The nozzles originally supplied with the plant were of the pattern shown in plate no. XXIX. These were of the deflecting type and as the governing did not prove satisfactory they were subsequently removed and nozzles of the type shown in plate no. XXIX were fitted. These are also of the deflecting type. The new nozzles consist of a steel disc with a circular orifice in the middle. A cap of the same metal is fixed to a lug cast on the disc, in the method shown in plate no. XXIX. The cap is operated by links and spindles and is attached to the governor terminal shaft, from which motion is transmitted to the nozzle by means of a pinion and rack. When the speed of the motor increases from a sudden decrease in the load the mechanism of the governor comes into action, deflects the nozzle cap, and causes the jet of water to shoot past the bottom bucket of the wheel. The motor at once slows up and the nozzle cap is again brought back to its normal position by action of the governor. **Nozzles.**

The governors for the water motors were made by * * * * * of Ashland, Mass., United States, America. Photo no. I shows the general appearance of the governor, which is of the above firm's "R" type and is fitted with a distant electric speed controller. A detailed description of this governor is given in Appendix B. **Governors.**

The alternators (see plate no. XXVIII) were made by * * * * * of Edinburgh, and are of their standard three-phase type with fixed armature and revolving field. Each machine is capable of developing 150 kilowatts at 6,600 volts, 500 R. P. M., 50 cycles. The alternators are mounted on a cast iron bed-plate of heavy section, with two bearings of the pedestal type. These are also made of cast iron, fitted with white metal bushes of ample length and lubricated by means of oil rings. **Alternators.**

The armature core is built up of charcoal iron sheet stampings assembled in a cast iron stator frame. The stampings are made in such a way as to form semi-closed tunnels, in which coils of the former-wound type are placed. These slots are insulated by means of mica tubes. In order to make the armature portable, the case is split into two sections. Sufficient spare coils were supplied to rewind three phases.

The field magnets are of steel, bolted to the centre hub by means of fitted studs, steady pins, and spring washers.

The shaft is of mild steel 6 inches in diameter. On it are secured two phosphor bronze slip rings provided with adjustable brush holders. The shaft is extended beyond the bearings at both ends to allow of the exciter armature and half couplings being fitted.

The exciters are compound wound four pole and have an output of 52 amperes, 110 volts at 500 R. P. M. The steel case is cast in one piece and mounted on an extension of the alternator bed-plate. The armature is carried on an extension of the magnet wheel shaft on which it is pressed. Each exciter has four sets of brush spindles fitted with double sets of radial type brush holders and carbon brushes. **Exciters.**

The switch board, which stands in a recess in the power station, consists of the panels, switches and instruments as detailed in the specification. It is so arranged that none of the high tension gear **Switch board.**

can be touched or come into contact with the control panels. The high tension main and feeder switches are operated by means of iron levers. All instrument transformers, oil switches, &c., are screened in with expanded metal. The general appearance of the switch board is shown in photo. no. II. Plate no. XXXI shows the diagram of connections. The wires connecting the machines to the switch board run underneath the power station floor in 3-inch earthenware ducts. The main exciter wires are 19/16 S. W. G. The wires to the shunt regulator are 3/18 S. W. G., whilst the wires from the alternators to the switch board are 3-cored, E. H. T., lead covered, paper insulated 7/16 S. W. G. cable. Trifurcating boxes filled with bitumen are used to join up this high tension cable to the machines and switch boards.

Lightning arresters. The lightning arresters at the power station are similar to those described in Section III of this chapter, with the exception that in the case of the power station arresters they have the original horn type arresters in parallel with them.

Leading out arrangements. As will be seen from the switch board diagram of connections, after the wires leave the feeder switches they pass through a set of choking coils, and thence through the power station walls. For this purpose 12-inch earthenware pipes are utilized, and glazed, in the same manner as in the sub-stations.

Station Lighting.

The power station, workshops, living quarters and roads are lighted and the workshops machinery driven by electricity at 220 volts for lighting and 380 volts for power. The pressure is reduced to 380 from the line voltage (6,600) by a 5-kilowatt transformer similar to those described in Section III of this chapter. The high tension switch for controlling this transformer is operated from the main switch board. At the foot of this local panel is also placed two three-pole quick break switches, one for the workshop machinery and the other for the lighting.

General notes.

The machinery at the power station has now been in operation for over three years and the following notes may be of interest.

Nozzles. The new type of nozzle of the Pelton wheel did not prove a success at first. It was inefficient (see plate no. XXIX.) When the new nozzles were first fitted, the machines only gave 75 per cent. of their output. To get over this difficulty the holes in the nozzles were bored out from their original size, $1\frac{1}{2}$ to $2\frac{1}{16}$ inches in diameter, which allowed the machine to take 50 per cent. overload. From tests made it is found that one machine on full load fitted with this new type of nozzle uses 3·6 cusecs. The nozzle is operated from the governor as shown in plate no. XXX by means of a rack and pinion. The spindle on which the rack has been fixed is much too light; consequently, unless very careful attention is given to the lubrication of the working parts which are subjected to the action of the water, this spindle promptly "corkscrews," and renders the governor useless. It is impossible to put in a heavier spindle due to the lack of metal on the boss of the rack, so to get over this trouble new racks are being made in the workshops with more metal on the boss which will allow of a stronger spindle being fitted.

It was originally intended to have nozzles of the spear type supplied. These would, of course, have been more economical but not so safe as the deflecting type.

A mistake was made in the construction of the Pelton wheels in that no door was fitted to the casing for the purpose of inspecting and lubricating the nozzle deflecting gear. This is a most important point, for as already stated the working parts of the gear exposed to the action of the water require good lubrication. As a temporary measure and until such time as doors can be fitted, automatic lubricators have been utilized. This has improved matters considerably. *Casing of the Pelton wheels.*

The 5-kilowatt transformer for the lighting of the station and workshops is placed behind the expanded metal screens which protect the high tension switch gear. This transformer should have been placed in an entirely separate compartment for this reason. When the transformer burns out, repairs cannot be effected without shutting down the entire plant. Unfortunately this transformer burns out very frequently as it is rather small for the work it has to do and also has to deal with current at 6,600 volts instead of 6,300 volts as it was designed for. The same applies to this transformer high tension fuses, which are also placed in such a way that it is impossible to get at them with current on. *Local transformer.*

The machinery in the workshops is good, what there is of it, but it is not sufficient to deal with the various break-downs that frequently happen on a scheme of this description, which is far removed from the usual engineering facilities. For instance had there been a few good machine tools available during the break-downs at the pumping station referred to in Section V of this chapter, repairs could have been carried out much quicker and better than they were. This matter has been put before the Board very strongly with the result that a shaping machine and drilling machine will be installed by the end of 1912. *Workshops.*

Up to the present the generators have not been run in parallel, except in paralleling tests. The load in the season is now too heavy for one machine between the hours of 7 p.m., and 9 p.m., hence it is necessary to run two machines. To do this, the high tension line is cut at a point which gives an equal load on both lines, thus each line has a separate machine to feed it. The station has been fed on this system throughout the season of 1912, and it has proved most satisfactory. *Running of the generators.*

SECTION NO. II—HIGH TENSION LINES.

These issue from the power station in two complete and independent sets and run together on the same poles for just over one mile, i. e. to a point immediately above the head works. Thence the lines diverge, one running to Mussoorie by the east and the other by the west, as shown in plate no. XXXIV on which the distances and sub-stations are marked. The total length of the high tension lines is approximately 11 miles. There are 462 spans, the average length of which is 120 feet. These high tension lines form what is known as a "ring system" of distribution. In all except two sub-stations—on branch lines—the mains pass through air-break isolating switches, so that it is possible to isolate one section of the line without interrupting the supply to any of the receiving stations.

The whole of the alignment was surveyed and laid out with a theodolite. The system adopted was to select two points between which the lines must run; then to travel over the ground between these two points, several times, until the best alignment had been roughly selected. This line was shown to the mate in charge of the survey coolies and the jungle clearing commenced. When this was done the line was again surveyed and set out as straight as possible, all angles being carefully measured. The average span was kept at 120 feet in order to adhere to the Indian Electricity Act. The line was then erected as explained in full detail in Appendix C.

As few joints as possible have been put in and these are all of the McIntyre type. This joint consists of a double tube of soft copper about 8 inches long into which the ends of the wire to be joined are pushed. The tips of the wire are bent over the ends of the tube and afterwards twisted up with two pairs of pliers and the whole joint thoroughly soldered. The strength of this joint is from 70 to 75 per cent. of the wire and it has a very good conductivity. All joints are so made as to be within 2 feet of an insulator when the mains are strained up.

The high tension lines are protected from lightning by means of a barbed wire secured as shown in plate no. XXXV by means of 2-inch staples driven into the pole top. This barbed wire is connected to earth at every pole by means of several turns of wire buried in the ground. At every twentieth pole a galvanized plate 3 feet square and one-eighth of an inch thick, to which the earth wire is attached, is buried 5 feet deep in the ground with a layer of charcoal one foot thick above and below the plate. Whenever possible the earth wire is carried to a stream and attached to an earth plate as described above which is buried in the bed of the stream. The erection of this barbed wire was a difficult matter and required great attention owing to the kinks and irregularities in it. Before securing this wire to the poles it was stretched with a dynamometer to remove the kinks referred to.

The next step after the fixing of the barbed wire was the erection of the guard nets. The type of guard net used is shown in plate no. XXXVI and was constructed in the following manner. The guard net brackets were fixed on supports similar to the standard type projecting 5 feet above the ground. At a distance of 150 feet another bracket was fixed in a similar fashion and between the two brackets the six longitudinal wires were stretched at a tension of 180 lb. In order to save wastage the wires were not cut, each wire being taken from a separate coil which was left lying at one end of the net. The wire at the "coil" end was secured by small iron clamps. The binders were fixed in the ordinary way commencing at one end. The first being fixed at a distance of about 4 feet away from the bracket to give sufficient wire to spare when the guard net was finally erected on the lines. The binders were spaced every 2 feet. Wooden distance pieces were used to keep the stretchers at the proper distance apart while the binders were being fixed. As the guard nets were made before the line was ready to receive them on each one was fixed a label, showing the crossing it was intended for. For transport, the guard nets were coiled into a bundle about 3 or 4 feet in diameter. A pole was passed through the centre and the net carried to its destination on the shoulders of two coolies.

At all angle posts, struts or stays are fixed, sometimes both, according to the nature of the ground. The struts used are ordinary line poles suitably cut and fixed to the pole by means of a ¾-inch galvanized iron bolt with square washers. A hole is dug in the required direction and the strut fixed against a foundation of stones well rammed into the hole.

The stays are composed of 7/16 B.W.G. galvanized iron wire. Two lengths of this wire are twisted together and are fastened at the pole (*a*) just above the top cross-arm and (*b*) just below the bottom cross-arm. The other end is attached to a galvanized iron stay bolt fitted with a bow and anchor plate as shown in plate no. XXXVI.

The anchor plate is buried in the ground at a depth of from 3 to 5 feet according to the nature of the ground.

A telephone is installed in each of the following buildings :—

(1) Power house.
(2) Pump ,,
(3) Office.
(4) Electrical Engineer's quarters.
(5) Head works.
(6) Sub-stations.

The instruments are of a type suitable for use in the neighbourhood of high tension lines. The receiver, transmitter and generator are specially insulated so as to avoid danger in case of contact between the telephone lines and the high tension conductors. Each instrument is fitted with fuses and surge dischargers. Under every instrument is placed an insulated platform. At the power house and pump house the telephone is placed in a separate building in order to avoid as far as possible the noise of the machinery. Extension bells are also fitted to these telephones and are placed in the houses of the men in charge of the various sections.

The telephone lines consist of two wires of no. 16 S.W.G., H.D.C., and are carried on the high tension poles by means of swan necks and insulators, to which the wire is bound with no. 18 S.W.G., H.D.C., the wires being transposed at every pole. In order to erect and use these telephones a seven years' licence was obtained from the Indian Telegraph department.

The high tension line and shackle insulators were supplied to the following specification :—

(1) Number required=3,000 and to be suitable for a 6,600 volt circuit.

(2) Insulators to be perfectly free from cracks, bubbles or pits, flaws and other defects likely to impair their strength, or in which moisture can lodge. If of porcelain the glaze should cover all the outer surfaces and be absolutely non-absorbent.

(3) Insulators should be subjected to the wet arcing test to determine the potential which will arc over them. A stream of water from a sprinkler

nozzle under a pressure of at least 50 lb. per square inch should be played on the insulator at an angle of 30 degrees. This will be somewhat similar to the conditions which exist in a rain and wind storm. The insulators should not arc over from the wire to the pin at less than 10,000 volts.

(4) Insulators to be provided with straight three-fourths of an inch galvanized bracket bolts complete with nuts and washers.

(5) Tenderers must specify the types of insulators offered and send drawings with full particulars as to insulation, resistance, maker's name, &c.

Insulators to the above specification, and of which full details are shown in plate no. XXXVI were supplied by a well-known English firm of insulator makers. These insulators had three petticoats and a recessed ring forming a neck about 1 inch from the top, also a semi-circular slot across the top. As will be seen from plate no. XXXVI they were supported on three-fourths of an inch galvanized iron pins which were screwed into the insulators and provided with a felt washer to take up any irregularities of the porcelain and to enable the bolt to be screwed home. When in position on the cross-arm there was a distance of $1\frac{3}{4}$ inches between the lowest part of the insulator and the cross-arm and a similar distance between the outside edge of the outermost petticoat and the iron pin.

These insulators were mostly erected during the year 1908 but did not come into regular use until May 1909, when current was switched on the lines for the first time. During and after the monsoon of that year twelve insulators broke down. During the year 1910 the insulators broke down in such numbers that hardly a day passed without the supply failing. The following list will show the serious nature of the trouble :—

Insulator failures.

From September 1909 to May 1910	21
May 1910	13
June „	77
July „	33
August „	185
September „	27
November „	31
December „	37
January 1911	15
March „	41
June „	2

The biggest daily record was on August 21st, 1910, when fifty-four insulators broke down. Photo no. VII shows a few typical examples of insulator break-downs.

When the insulators began to fail in 1909 the matter was considered by the Electrical Inspector and the Sanitary Engineer to Government. Their report was as follows :—

" *Insulators.*—We examined several of the line insulators which have broken down electrically during the last rains. The failure in our opinion is due to the insulator not being altogether suitable for Indian monsoon conditions. The bolt is screwed into the insulator and is provided with a felt washer to take up any irregularities of the porcelain and enable the bolt to be screwed home. The insulators are provided with a rough screw thread to receive the bolt. This screw thread is unglazed as it would be well nigh impossible to glaze it. What we think takes place is that the felt washer becomes soaked with water and the unglazed screw threads of the insulator absorb the water until the whole of the top of the insulator under the glazing is a semi-conductor at nearly earth potential, since the poles, when soaked, may be taken as fairly good conductors. The insulating quality of the insulator in this state depends on the outside glazing which, if perfect, may stand the strain, but if imperfect in the slightest degree will break down and the top is then snapped off the insulator by the current as it passes from the wire to the bolt. Fortunately only a few of the insulators have failed in this way, and these have been in places where the bolt of the insulator has been at earth potential (i.e. where insulators have been used on an iron bracket which has been well earthed); we think that very considerable trouble would have been experienced with this type of insulators had they been used with iron poles, and it would be well to change the type of insulator when buying a fresh lot. The felt washer used with bolts in our opinion is not a good practice for India. It would have been better if the bolts had been cemented solid into the insulators, as this would protect the unglazed screw of the insulator from moisture instead of providing moisture for this part to absorb as the felt washer seems to do. We suggest that where these insulators are fitted on iron brackets or fixed on to the walls of buildings, the bolts be cemented in with a good cement, say litharge and glycerine or gelatine and acetic acid and felt washers be done away with.

" When purchasing new insulators a different type ought to be obtained. We think that an insulator with a much wider 'shed' and more porcelain between the bolt and the wire grooves and the bolt cemented into the insulator would be found to give every satisfaction.

" The high tension shackle insulators are also failing. This we think is also due to the insulator not being suitable for monsoon conditions. These insulators require to be much larger overall and a greater factor of safety allowed. They may be quite satisfactory on a much higher tension under less severe climatic conditions, but with rainfalls such as we get in Mussoorie the corrugations on which the insulator greatly depends for its insulating properties are very little good as the whole of the corrugations may be submerged in a sheet of water. All the shackle insulators failing ought to be replaced with insulators of very much larger dimensions.

" The question of the insulators failing ought to be taken up with the suppliers. They may be able to replace those which have failed by insulators of a larger and better type."

In July 1910 the number of insulator break-downs became so numerous that it was necessary to consider the question of changing the insulators entirely. In order that the matter could be taken up with the makers it was resolved to carry out as accurate tests as possible at the power house. The results of this will be found in the following report :—

" Considerable trouble has been experienced from the high tension insulators on the transmission line breaking down. This trouble is chiefly experienced in the monsoon season and also in a slighter degree during the winter rains, and is caused by the current leaking from the wire to the bolt, which supports the insulator on the cross-arm. The faults on the insulators develop slowly. The faulty insulator first shows signs of weakness by a slight glow or phosphorescent light appearing on the binding wire which binds the line wire round the neck of the insulator. This continues for some time, gradually increasing, and then violent snapping sparks take place. The porcelain between the wire and the bolt becomes very hot due to current leaking to earth, and in many instances the heat has been sufficient to melt the porcelain insulator before the leakage current was sufficient to cause the automatic devices to operate at the power house.

" In a previous note it was pointed out (from the experience gained during the first monsoon in which these insulators were in service) that these insulators were not satisfactory, and it was suggested that the matter should be taken up with the makers.

" We are now more than ever convinced that these insulators are not suitable for the system in Mussoorie and that satisfactory working of the high tension transmission lines will not be possible until the whole of the insulators are replaced by insulators of greater insulating qualities.

"The system is alternating current three-phase at 6,600 volts with the neutral point 'earthed.' The tension between the wire and the pin of the insulators will therefore be 6,600/√3, or 3,815 volts alternating, at which voltage the insulators are failing.

"Two insulators (nos. 12 and 13), which had shown signs of failing while in service on the line, were tested (dry) by applying an alternating pressure between the bolt of the insulator and a wire bound round the neck of the insulator to resemble actual working conditions. The pressure was gradually raised to 9,515 volts and the first insulator broke down in four minutes. The second insulator broke down when a pressure of 7,785 volts had been applied for four minutes.

"The tops of the insulators were shattered and the pins were found to be very hot which shows that considerable current was leaking before break-down took place.

"Three new insulators (which had not been in service) were subjected to a similar test; a pressure of 10,000 volts alternating was applied at which the wire round the neck of the insulator glowed freely but the insulator did not break down. This shows that the insulating properties of the insulators deteriorate enormously after the insulators have been in service for some time under the normal weather conditions obtaining in Mussoorie.

"Unfortunately instruments and appliances necessary to carry out accurate tests of insulators were not available, but the above tests prove that the insulators are unsuitable for working conditions obtaining in Mussoorie.

"The specification test for these insulators was as follows :—

"'The insulators in class (*a*) (high tension insulators) should be subjected to the wet arcing test to determine the potential which will arc over them. A stream of water from a sprinkler nozzle under a pressure of at least 50 lb. per square inch should be played on the insulator at an angle of 30 degrees. This will be somewhat similar to the conditions which exist in a rain and wind storm. The insulators should not arc over from the wire to the pin at less than 10,000 volts.'

"The test was applied to ten insulators taken at random from a stock of new insulators which had not been in use.

"The results are shown in tabulated form for ready reference :—

No.	Insulator.	Sparking voltage.	Arcing voltage.	Time before arcing takes place after voltage is raised.	Remarks.
1	A ..	..	8,996	1 minute.	
2	" ..	5,190	8,650		
3	" ..	5,190	8,304		
4	" ..	6,055	10,034	10 seconds.	
5	" ..	5,709	8,304		
6	" ..	5,536	9,515		
7	" ..	5,190	9,342		
8	" ..	5,190	9,342		
9	" ..	5,190	8,996		
10	" ..	6,055	9,515	15 seconds.	
11	Shackle ..	5,190	8,996		
12	" ..	5,190	9,515	} 4 minutes ..	Dry test.
13	" ..	..	7,785		

"It will be noted that only one out of the ten insulators did not arc at a much lower voltage than the specified 10,000 volts.

"Each insulator under the test was discharging freely to the pin at the voltage noted under 'Sparking voltage' and the insulators in many cases would have 'arced' at much lower voltages if sufficient time had been allowed between each alteration in pressure.

"It will be seen from the above that the insulators are not in accordance with the specification and we have no hesitation in stating that the insulators are not satisfactory for 6,600 volts alternating current when working under the climatic conditions prevailing in Mussoorie, and strongly recommend the Municipal Board to endeavour to come to some arrangement with the makers to replace the whole of the insulators and provide others of a suitable type."

As a result of the above tests the Board took the matter up with the makers who replied that the insulators were up to the specification and that they could not see their way to help the Board in the matter.

It was then decided to have proper tests made and to get an authoritative expert opinion on the case. Accordingly a box containing twelve unused insulators was sent to a firm of well-known consulting engineers in London. In due course a report on the tests was received which was briefly as follows: The insulators mounted on wooden cross-arms with their own bolts had a main conductor secured to the slot on the top by binding wire bound round the neck. An alternating current of 50 cycles was applied between the conductor and the bolt. Water was played on the insulators from a 2-inch nozzle at a pressure of 50 lb. to the square inch. The pressure was increased to 4,000 volts and at this voltage sparks passed from the conductor to the arm. On the voltage being increased to 9,000 volts the flash over was continuous.

The water was turned off and the test continued, the voltage being increased to 32,000 volts; at this pressure one of the insulators broke down due to a puncture from the neck to the pin, the head of the insulator and pin being hot. A new dry insulator was then tested which broke down at 36,000 volts in a similar manner to the first.

In addition to the above tests, it was resolved to see if prolonged soaking in water had any effect on the efficiency of the insulators. For this purpose two of them were specially dried in an electrically heated oven, the temperature of which was maintained constant at 80 degrees C. for 24 hours. Another two insulators were inverted and the hole for the bolt filled with water. This pair was allowed to soak for 66 hours. On testing it was found that the dry insulators stood 50,000 volts before arcing to the pin. The soaked insulators stood up to 30,000 volts. This voltage was not increased as it was not desired to puncture the insulator. While the saturated insulators were under test the whole insulator assumed a "glowing" appearance particularly in the centre of the top groove, where there is only about a quarter of an inch between the bottom of the groove and the top of the hole for the bolt. These insulators were afterwards dried and one of them broke down at 46,000 volts.

In a letter covering their report the consulting engineers stated that the tests clearly showed that the insulators were not up to the specification, that the size of the insulators was too small and that the distance from the edge of the outer petticoat was too short.

On receipt of this report, it was resolved, as the matter was most urgent, to get a new lot of insulators at once. A specification was drawn up by the Electrical Engineer on the following lines:—

"SPECIFICATION FOR HIGH TENSION INSULATORS FOR THE MUSSOORIE HYDRO-ELECTRIC SCHEME.

Three-phase star connected system.
Maximum working voltage between phases = 6,600 volts.
Voltage from any phase to earth = 3,815 „
Maximum available load ... ... 45 amperes per phase.
„ actual to date ... ... 20 „ „ „
Size of copper wire no. 7 S. W. G.

"High tension insulators to be (1) of white porcelain glazed overall; (2) five petticoated; (3) minimum diameter of shed to be 8 inches; (4) of the pin-cemented-into-insulator type; (5) able to receive a pin three-fourths of an inch in diameter with space for cementing.

"Insulators must not break down under the following conditions :—

"Continuous and heavy rain for three months on end, the fall being as much as 140 inches during these three months, as great as 20 inches in twenty-four hours and as heavy as 9 inches in three hours. To ensure which the following test must be applied.

"Wet arcing test, 20,000 volts alternating current, to be applied between the wire on neck of insulator, and the pin, for three hours continuously without arcing over from the wire to the pin. The pressure then to be gradually raised until an arc is formed and this arcing potential to be observed.

"The wet arcing test to be carried out as follows :—

"A stream of water from a sprinkler nozzle not less than 2 inches in diameter, under a pressure of not less than 50 lb. per square inch, should be played on the insulator, on the wire and the pin, at an angle of 30 degrees. The stream of water must be continuous and must be evenly distributed over the insulator, the wire and the pin, in order to approximate as near as possible to conditions existing during a violent rain and wind storm. The distance between the lowest point of insulator and wooden cross-arm (on which the insulator pin must be fixed during test), to be carefully noted and not to be less than 5 inches. The insulators under test must be fixed to galvanized iron pins of the specified diameter and cemented thereon with either a mixture of glycerine and litharge, or else, pure Portland cement, the material used to be specified in the record of test."

Tenders were received from all the leading firms of insulator makers, that of * * * * * of Victoria, New York, being accepted. The appearance and construction of the new insulators are shown in plate no. XXXVI.

The makers' specification of the insulators is as follows :—

Line voltage	...	...	... 33,000
Test "	...	...	... 100,000
Rain test	...	...	... 60,000
Leakage distance	...	...	19½ inches
Striking "	...	...	4⅜ "
Size of pin hole	...	...	1⅝ "
Net weight	...	...	7⅛ lb.

The insulators were tested at the makers and the test sworn to before a Public Notary as follows :—

"The insulator was mounted on a solid steel pin of the proper diameter and with a half inch cable tied in the regular manner into the top and the side wire grooves.

"Under these conditions the dry flash over potential was 93,000 volts. The insulator was then subjected to a rain of 1 inch in 5 minutes precipitation, thrown at an angle of 45 degrees for three hours continuously and at 20,000 volts no distress whatever showed. At the end of three hours it was necessary to raise the potential to 60,000 volts before the flash over occurred. The distance from the cross-arm to the bottom of the insulator was 5½ inches and the attachment between the insulator and pin, neat Portland cement.

"The method of fixing the bolt to the insulator was as follows :—A large number of wooden cones were turned up with a central hole of the same diameter as the insulator bolt. These cones were split to enable them to clear the collar of the bolt. Pure Portland cement was used for fixing the bolt to the insulator, mixed in the proportion of 80 parts cement to 20 parts water by weight. The insulator was inverted and cement was placed round the bolt and carefully rammed down to ensure the cement getting into the threads of the screws of the insulator and bolt. When this operation was completed the wooden cone was slipped over the bolt and fitting exactly to the taper of the insulator petticoat, kept the bolt in a true vertical position. The insulators were allowed to stand for fourteen days in order to give the cement time to set."

The new insulators have now withstood two monsoons and no electrical break-downs have been experienced. The only break-downs have been mechanical and were caused by school boys throwing stones at the insulators. It is interesting to note that, although the insulators had all three petticoats damaged, nothing happened. Luckily it was in the dry season.

The trouble experienced with the high tension insulators should prove a salutary lesson to all who may be called upon to design and construct high tension lines in India and is a good example of the evil results which follow a loosely worded specification. The makers stated that the insulators were tested according to the specification and proved satisfactory. It will be noticed in the original specification that the element of time was ignored and that the size of the sprinkler nozzle was not specified.

The difference in the results of the tests of the makers on the one hand and the consulting engineers on the other, was due to obvious reasons. The latter used a large nozzle and a continuous stream of water, while the former apparently used a small nozzle and an intermittent flow of water for a short period.

CRITICISM AND NOTES ON THE HIGH TENSION LINES.

One of the chief mistakes made in connection with the construction of the high tension lines was the use of wooden poles. Why these were ever used it is difficult to see especially as those who were responsible for the drawing up of the scheme had the benefit of the experience of the Indian Telegraph department to aid them. The municipality have been put to the expense of changing every wooden pole throughout the entire distribution system. Had the poles used been well seasoned they would probably have lasted a few years longer, but even then they would have been far from satisfactory. The poles purchased were of all shapes, sizes, and lengths and quite unseasoned, the result of the latter being that after the poles had been erected about two years the outer shell rotted to such an extent that many of the poles broke off at the ground line, for it is under the ground line that this decay is worst.

The method of fixing the cross-arms is also bad. As will be seen from plate no. XXXV the cross-arms are fixed by means of bolts passing through the centre of the pole. Now in these *sal* poles there is a hard core varying from 2 inches to 4 inches in diameter which if not exposed to moisture is the strongest section of the pole, but if a large hole is bored through this core into which the rain is conducted by means of the fixing bolt, it very speedily becomes as rotten as the outside shell. This has happened on these poles and cases of them snapping off are numerous.

Another bad point is the fixing of the barbed wire by means of 2-inch staples. When the poles were first erected and the wood was green these staples were sufficient to hold the wire, but when the rains commenced and the top of the pole started to rot the staples could hardly sustain the strain due to the weight of the wire and the first breeze that came along at once pulled the wire and its fastenings clean off the pole and this short circuiting of the mains of course shut down the plant until repairs could be effected.

Opponents of the overhead earth wire contend that it is apt to break and fall on the mains. This has not happened here yet; the only trouble experienced has been due to the fastenings becoming undone owing to rot as mentioned above. The wire used is, however, not considered strong enough mechanically for the longer spans and it would be advisable in future to use stranded steel cable as used for guys.

The construction for the first mile of the high tension distribution is very bad. The idea of the "loop" system is that in the event of one line breaking down, the station can be fed from the other while repairs are being carried out to the damaged section. A glance at plate no. XXXIV will show that the mains run on the same set of poles to a point just above the head works. Now in the event of an accident to one of the lines it is impossible to carry out repairs without shutting down the plant, as the two lines are within a few inches of each other. Again, if there is a landslip on this section the chances are that a pole will go and the plant will be shut down until such time as a new pole can be erected.

In constructing the high tension line a mistake was made in adhering so closely to the rules framed under the Indian Electricity Act with reference to the length of span. Owing to the short spans there are a great number of acute angles on the lines where they follow the contour of the hills. These angles throw a great strain on the insulators and binders, and it would have been a much better, cheaper, and more efficient construction to take moderate spans of about 200 to 300 feet.

Another mistake was made in running the telephone lines on the same pole as the high tension wires. Telephones are most required when a break-down occurs and when the break-down is on the lines the telephone is generally put out of gear as well. The size of wire used is also mechanically weak and in a severe wind storm often breaks. It is also unnecessary expense to use copper wire. No. 12 S.W.G. galvanized iron wire would have been much more suitable.

The guard nets were made to the Board of Trade specification, but it is considered that the binders are fixed too close together. Had these been spaced at 4 feet instead of 2 feet apart, they would have answered their purpose equally well and reduced the strain on the stretchers considerably.

Reconstruction of high tension lines.

As the result of a report made by the Electrical Engineer on the state of the high tension lines at the end of 1911, the Board decided to act on his advice and get rid of the wooden poles. The new poles will be of the Hamilton type and spans of an average length of 200 feet will be employed; for short spans up to 150 feet single poles of B.C.D. sections will be utilized, but where guard nets and longer spans are necessary coupled poles will be used. Plate no. XXXVII shows the arrangement of the new construction with guard net brackets, barbed wire clamps, &c. The alignment on the first section of the high tension lines will be altered. The dotted line on plate no. XXXIV shows the route from the power house to the first sub-station. This is being done to keep the two lines as far apart as possible and thus obviate the likelihood of a landslip putting both lines out of action at the same time ; also to allow of repairs being carried out to one line while current is fed to the station by the other.

It is still intended to carry the telephone wire on the high tension poles, but the wire used will be no. 12 S. W. G., G. I wire. Further, a separate line is being run from the office to the power house and pump house. This is being done as it is considered most essential to have an uninterrupted telephonic communication between the above mentioned places.

SECTION NO. III.—SUB-STATIONS.

There are in all twelve sub-stations in the distribution system situated in the positions marked on plate no. XXXIV. A reference to the sub-station buildings will be found in chapter II. Photos nos. VIII, IX and X show (*a*) the exterior, (*b*) the interior, and (*c*) a view looking upwards in the tower. The original method of leading the high tension wires into the tower is shown in plate no. XXXVIII while the same plate also shows the modification brought about in this arrangement by the advent of the new insulators. In two of the three large sub-stations the method of leading-in varies somewhat from the standard, but it is to all intents and purposes the same. In the standard sub-station the high tension wires pass into and out of the tower through three 12-inch earthenware pipes which are glazed in by means of split circular pieces of glass, cut to fit the mouth of the pipe and held in position by means of a thin metal flange. In the middle of the glass a 1-inch hole is cut to allow of the wire passing through without actually touching the glass. These leading-in pipes are glazed on the inside only, as shown in plate no. XXXVIII. In the two large sub-stations the wires enter through an oblong window (see photos nos. VIII and X), the insulators being carried on channel irons fixed into the sides of the window as shown in photo no. VIII. This window is glazed in, in the ordinary manner, and also has 1-inch circular holes cut in the glass to allow the wires to enter the tower. As will be seen from plate no. XXXVIII each wire passes straight through the towers, but by means of the double sets of isolating switches current may be cut off either at the incoming or outgoing sides. The bottom terminals of these switches are cross-connected and from the cross connections tappings are taken to the transformer and lightning arrester as shown in plate no. XXXIX.

The lightning arresters supplied by the contractors with the plant were of the horn type. These, however, did not prove sufficient to deal with the very severe lightning storms which at certain periods of the year prevail in Mussoorie. It was resolved to try a new type. Having in stock a large number of what is known as the multi-gap type of arrester, it was suggested by the Electrical Inspector to Government that experiments might be carried out with these. His suggestions were adopted and experiments were carried out at the power house. It was found that by putting four of these arresters in series that they operated at approximately 10,000 volts. This type of arrester was accordingly adopted and has so far proved fairly satisfactory. Its general arrangement is shown in plate no. XL. The arrester consists of three limbs, one to each phase. Each limb is made up of four 2,000 volt arresters connected in series. As will be seen from plate no. XL this type of arrester consists of a large number of small cylinders which are made of a special non-arcing metal and arranged with small air gaps between them. In "shunt" with part of the gaps is fixed a non-inductive resistance consisting of a special alloy of carbon and metal. The cylinders are mounted on porcelain slabs which are in turn mounted on a strip of well varnished teak wood. The whole arrester is assembled on iron brackets secured to the wall by means of rag bolts. A high tension insulator of the bus bar type is fixed between the teak wood strip and the iron bracket. Approximately three-fourths of the gaps are shunted by means of the non-inductive resistances. The remaining fourth or upper section of the arrester is unshunted, the line being connected to the first cylinder. The last four gaps are short circuited by small brass strips and the last cylinders of each limb are cross-connected by means of a heavy brass strip which is connected securely to earth by a copper wire of heavy section.

The action of this type of arrester is as follows :—

From the experiments carried out it was found that with nine gaps unshunted and twenty-three gaps shunted by means of the non-inductive resistances, the arrester operated at approximately 10,000 volts. Under normal conditions the earth potential is brought up to the top of the uppermost shunt resistance. Now let us consider what happens when an increase of potential occurs on the lines due to a discharge of lightning. The first thing is the break-down of the non-shunted air gaps, next the shunted gaps break down. The arc is, however, not maintained so that the current passes through the shunt resistance. The non-shunted gaps have now the shunt resistance in series with them and thus reducing the current, quickly extinguish the arc. This extinguishing is also helped by the non-arcing nature of the metal of the cylinders.

From the top of the lightning arresters the high tension wires run through three choking coils to the high tension oil switch which is mounted at the back of the sub-station switch board. The general arrangement of this board is shown in plate no. XLI and photo no. IX. From the high tension oil switch current is conveyed to the high tension side of the transformer by means of a high tension three-cored lead-covered cable, at both ends of which are trifurcating boxes. This cable runs under the sub-station floor in a 3-inch earthenware duct. After leaving the trifurcating box the high tension current passes through another oil switch fixed on to the transformer case, and then through a set of fuses before finally reaching the high tension side of the transformer.

The specification for the sub-station plant including transformer, switch gear, &c., was as follows :—

1. The contractor to supply and deliver, erect, joint, fix and finish complete in pits or sub-stations provided for the purpose by the municipality the transformers hereinafter specified, with all switches, fuses and other necessary apparatus for their safe and efficient working.

2. Transformers to 11 in number, of the size specified below :—

1	Transformer of 70 K. W. capacity.	
1	" " 50 " "	
2	" " 40 " "	each.
2	" " 15 " "	"
3	" " 10 " "	"
1	" " 5 " "	
1	" " 5 " "	For station lighting and workshop machines, &c.

3. Each transformer to be capable of continuously giving the specified output in the secondary circuit at an E. M. F. of 380 volts between the principal conductors, the primary circuit being arranged for a pressure of 6,600 to 6,300 volts at a periodicity of 50 complete alternations per second.

4. Transformers to be all of the same type (three-core) and those of the same size to have their corresponding parts strictly interchangeable. They must be mounted in water-tight cast iron boxes of ample size.

5. Switches and fuses are to be provided on both high and low tension sides of each transformer arranged in a water-tight box so as to be readily accessible, and provision must be made for disconnecting and withdrawing the transformers without the current being switched off to either the high or low tension mains. All switches and fuses to be so constructed as to reduce the danger of arcing to a minimum. High tension terminals to be efficiently protected.

6. Each transformer before being used on the circuit must be tested for one hour at a pressure of 15,000 volts alternating applied between the primary and secondary coils, and between the primary coils and the core and case without injury or break-down.

7. No accessible part of any transformer to have a temperature exceeding 50 degrees F. above the surrounding air when running continuously at full load.

8. The drop of E. M. F. on the secondary coils shall not be more than 2½ per cent. at full non-inductive load when the primary pressure remains constant.

9. The total open circuit loss of any transformer should not be more than 2½ per cent. of the secondary load.

10. Tenderers must fill in the guaranteed efficiencies in the annexed table:—

GUARANTEED EFFICIENCIES.

	70 K. W.	50 K. W.	40 K. W.	15 K. W.	10. K. W.	5. K. W.
Full load ...						
3/4 " ...						
1/2 " ...						
1/4 " ...						
1/10 " ...						

11. All lighting will be on the four-wire system with a pressure of 380 volts between the principal conductors and 220 volts between the three conductors and the neutral wire at full load.

12. Complete particulars of the transformers are to accompany the tenders, together with drawings showing the arrangement of the various parts and the sizes of the transformer chambers required.

13. The following spare parts are to be supplied for each transformer :—

1 dozen high tension fuses.
1 " low " "
1 complete set of primary and secondary windings.

Transformer switch boards.—Each transformer house to have a marble switch board fitted with the following :—

High tension side.—3 Lightning arresters with earth-plate.
1 Triple pole high tension switch with fuses.

Low tension side.—6 Lightning arresters, with earth-plate.
2 Triple pole low tension switches with fuses. One for street lamps and one for house distribution.

The transformers supplied did not correspond with the above specification as regards outputs, which are actually as follows :—

4 Transformers of 30 kilowatts.
6 ,, of 10 ,,
2 ,, of 5 ,,

With one spare of each size complete.

These transformers are of the three-cored oil-cooled shell type and are star connected, the low tension coils being placed inside the high tension coils. Plate no. XLII shows the general arrangement of the transformers.

The low tension current passes from the transformer through a three-pole switch and fuses by means of insulated rubber cable to the switch board. These cables are also laid underground in a 3-inch earthenware duct. At the switch board they are connected to the bus bars as shown in plate no. XXXIX. The current then passes through two three-pole feeder switches and fuses. One of these switches is for public lighting and one for house lighting. From these fuses current passes through choking coils and lightning arresters of the Wurtz type up to the low tension leading-out tubes in the tower which consist of a similar arrangement to that shown in plate no. XXXVIII. The action of the Wurtz type arrester is practically similar to that of the multi-gap arrester described above.

The neutral wire is earthed and does not pass through any switches or fuses. A tapping is taken off one of the phases and neutral for sub-station lighting.

CRITICISM OF SUB-STATIONS.

The design of the sub-stations on this system is not good and leaves much to be desired.

The first defect is the small size of the buildings. It is true that with the present arrangement of wires inside the sub-stations there is room to operate the switches with a fair degree of safety to the operator but the buildings should have been larger for convenient working. The arrangement of high tension and low tension wires in the tower is also imperfect. In many cases there is insufficient space between the high tension and low tension wires. There are at present two sets of high tension isolating switches placed near the top of the towers; to work these, the operator has to stand on an insulated platform with his back towards the back of the switch board. His head is then only a short distance away from the high tension wires on the switch board, which are unprotected. A third set of isolating switches should have been provided to enable current to be cut off any sub-station without cutting off the supply from any of the other stations as it is frequently necessary to examine the switch board insulators and lightning arresters. The type of lightning arresters in use has proved fairly satisfactory but there is still room for improvement. The theory of lightning arresters is not as yet properly understood and most of the well-known electrical engineers have opinions on this subject which are as varied as they are numerous. The horn, multi-gap, water-jet and electrolytic types have each got their own advocates, whilst several consider lightning arresters quite unnecessary. But it should be noted that very few of these are actually in charge of plants subject to severe lightning storms. All these arresters have their good and bad points. The fact of the matter is that an arrester which will work well on one plant in one locality will not do so on a similar plant in another locality. The trouble experienced with the horn arresters at Mussoorie was that during a heavy discharge they formed a "short" and threw the "trip gear." Had a resistance been inserted with this type of arrester it would probably have worked quite as well, if not better, than the multi-gap type. It is generally admitted that the shunt resistance rods of the multi-gap type arrester are not sufficient to deal with severe lightning discharges and many cases have been experienced on these works where the resistance rods have been reduced to cinder. The efficiency of the present type of the lightning arresters would be greatly enhanced if a series resistance could be inserted as well as a shunt. With regard to the so-called non-arcing metal of which the cylinders are made, this is very doubtful as on many occasions distinct signs of arcing have been noticed in these arresters. The main point about the multi-gap and horn-type lightning arresters is not so much the efficiency of the arrester itself as the value of the series resistance to be inserted. This can only be found by "trial and error" and the resistance that may prove suitable for storms in one locality will not be suitable for storms in another. With regard to the barbed wire as a lightning protector opinions vary somewhat, but on the whole it has proved a distinct success on this scheme. On several occasions it has been necessary to cut away a number of spans of the barbed wire during the monsoon due to the wire being pulled off the pole tops and thus leaving part of the lines without protection from lightning. On these occasions it has been noticed that during lightning storms the trip gear has acted frequently. This can only be put down to the absence of the barbed wire on the section in question.

In the working out of the sizes of the transformers for the various sub-stations it was not right to assume that the capacity of each would be according to the demands made before the public realized the benefits of electricity. It was a still greater mistake to order transformers of so many different sizes, as it means keeping in stock so many different sizes of spare parts. Further, a sub-station consisting of two 20 kilowatt transformers is better than one consisting of one 40 kilowatt, where efficiency is not the primary consideration, as it is unlikely that two transformers will break down at one and the same time. It would have been much better to have ordered a standard size of transformer, say 20 K. W. It is a bad principle to assume your total likely load and to have the sum of your sub-station outputs equal to this. If it is necessary to have spare generators at the main station, it is equally necessary to have, in each sub-station, one or more spare transformers. This fact has been amply proved in Mussoorie where the capacity of each sub-station has had to be practically doubled. Another mistake in the design of the sub-stations was the running of the high and low tension mains in earthenware ducts, as in the event of a break-down in the cables it is a difficult matter to get at the seat of the trouble. A much better arrangement would have been to have channels cut in the sub-station floor with a suitable covering of planks or iron plates which could be easily removed. At present if a break-down occurs in a cable it means pulling up the whole of the sub-station floor. With regard to the working of transformers in parallel on a similar scheme to this it is not a bad principle to go on, to work in groups of fours. Under normal conditions each transformer should work at just under full load, and, if necessary, in the event of a break-down, the remaining three transformers should take up the load of four by working at a slight over load for a short time. A transformer should not be worked at over full load for any length of time. The design of high tension fuses on the Mussoorie transformers is bad and if fuses were employed at all they should have been of the oil type, but it would have been better to have had reliable automatic trip gears on each transformer instead of fuses.

Considerable trouble was experienced when the scheme first began to work with transformers burning out. This was partly due to their not being properly dried before being put on load. Transformers of this size and voltage should be dried out for a period of not less than 24 hours at a temperature of 180 degrees F. Where current is available, a suitable way of doing this is to dry them out in pairs applying low tension current to the high tension side of no. 1 transformer and connecting the low tension of no. 1 to the low tension of no. 2 while the high tension of no. 2 should be short-circuited. Thermometers should be carefully placed between the windings and as soon as the temperature goes up above 180 degrees F. current should be switched off until the temperature falls about 150 degrees F. When this temperature is reached current may be switched on again. Whilst transformers are drying out they should be carefully watched during the whole period.

SECTION NO. IV.—LOW TENSION LINES.

The low tension distribution system consists of two entirely separate sets of phase wires, with a common neutral carried on the same poles. One set is for private lighting and the other for road lighting. Plate no. XLIII shows a typical section of the low tension distribution, from which the run of the wires can be easily traced. On the principal sections of the distribution it is possible to link up one or more sub-stations in parallel. This is done at a switch pole which is described in another part of this Section.

The total length of the low tension distribution is approximately 19 miles. The wires are carried on single *sal* wood poles. The average length of span is about 150 feet. The insulators are carried on 2-foot × 4-inch × 4-inch cross-arms which are secured to the poles by means of U shaped bolts. Plate no. XLIV shows the type of pole used for distribution purposes, i.e. where the wires issue from the sub-stations and tap off in various directions. Poles of similar construction to this are utilized where bad angles occur but instead of the angle iron rings ordinary cross-arms are used. The insulators are of white porcelain and are shown in plate no. XLIV. The neutral wire is carried on the top of the pole by means of 4-inch galvanized iron nails. The top of each pole is protected by means of a roof. This is fixed under the saddle and is kept in position by the saddle nails. The shape and material of the pole roof is similar in all respects to the one in use on the high tension lines.

At all angles, poles are stayed or strutted. The bracket for the stay wire is fixed at the top of the pole and is made of sufficient length to ensure the stay wire being well clear of the mains.

Where the low tension mains cross over the Telegraph department lines, guard nets are utilized. Latterly a new type of guard has been introduced; this is shown in plate no. XLIV. The guard consists of a small copper hook which is connected to the neutral wire. In the event of a phase wire breaking, it at once comes into contact with this hook and immediately blows the fuse in the sub-station controlling the circuit in question.

The distribution system was calculated in the following manner:—

The capacity of the sub-stations was fixed according to the estimated number of houses and road lamps to be supplied from each.

From this estimate and the following formulae the different voltages were calculated for each centre of distribution :—

(1) $$C = \frac{W}{E \sqrt{3} \times \text{Cos.}\,\phi}$$

Where C = Current in amperes.
W = Load in kilowatts.
E = Voltage at receivers.
Cos. ϕ = Power factor (taken as ·75).

(The full load of the transformers being 190 K. W., a load of 200 K. W. was assumed as a basis for calculations.)

(2) Voltage drop due to resistance = CR
Where C = current.
R = resistance.

N.B.—The resistance varying with the temperature of the wire all calculations were based on a maximum temperature of 140 degrees F. This was not quite correct as the maximum load is only on at night and thus in subsequent and final calculation the temperature has been taken as 60 degrees F.

The resistance of a unit length (one yard) of copper wire being known at 60 degrees F, the resistance at a higher temperature is found from the following formula :—

$$R\,t' = R\,t + (R\,t \times \cdot 00238\ t).$$

Where R t = Resistance per unit length at 60 degrees F.
R t′ = „ „ at higher temperature.
t = difference of temperature in degrees F.

The voltage drop due to induction is given by :—

$EL = 2 \pi n l c.$

Where EL = Inductive drop.

2π = a constant = 6·28.

L = Inductance of the line in Henrys.

c = Current.

n = Periodicity.

L is found from Maxwell's formula for parallel conductors :—

$$L = \frac{2 l}{(10)^9} \left\{ 15 \cdot 24 + 140 \cdot 366 \log \frac{d}{r} \right\}$$

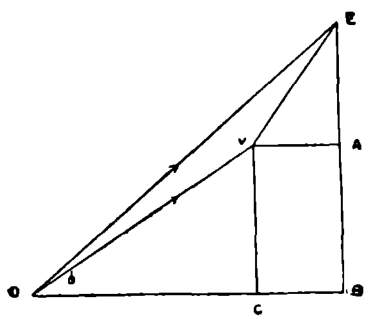
Where l = length of line in feet.

d = distance between centres of wires in inches.

r = radius of conductor.

Remaining figures are constants.

The phase relation of these drops has next to be considered. This can be seen from the following diagram :—



V E = Impedance of circuit.

V A = Volts lost due to ohmic resistance.

E A = Volts lost due to inductive resistance.

O C = phase position of current.

O E = generator voltage.

O V = voltage at receiver.

$O E^2 = O B^2 + E B^2$

$O E^2 = (O C + V A)^2 + (E A + V C)^2.$

Taking Cos. ϕ = ·75, Sin. ϕ = ·662.

Therefore $O E^2 = (O V \text{ Cos. } \phi + V A)^2 + (O V \text{ Sin. } \phi + E A)^2.$

The problem is then worked out by algebraical methods. To give an example :—

Suppose V A = 104 volts.

E A = 115 volts.

O E = 6,600 volts.

Then $6{,}600^2 = (O V \text{ Cos. } \phi + 104)^2 + (O V \text{ Sin. } \phi + 115)^2.$

Therefore $4{,}35{,}60{,}000 = O V^2 + 308 \; O V + 24{,}041.$

$O V^2 + 308 \; O V = 4{,}35{,}35{,}959.$

Now $O V^2 + 308 \; O V + \left(\frac{308}{2}\right)^2 = 4{,}35{,}35{,}959 + \left(\frac{308}{2}\right)^2.$

Therefore $\left(O V + \frac{308}{2}\right)^2 = 4{,}35{,}35{,}959 + \frac{94{,}864}{4} = \frac{17{,}42{,}39{,}700}{4} = \left(\frac{13{,}200}{2}\right).$

Therefore $O V = \frac{13{,}200 - 308}{2}$

$O V = \frac{12{,}892}{2}.$

$O V = 6{,}446$

Knowing the voltage ratio of the transformer to be 6300/380 the voltage between any phase and the neutral is easily found thus :—

$$\frac{380}{6300} \times \frac{6,446}{\sqrt{3}} = 225 \cdot 1 \text{ volts.}$$

Having started with full load and the full generator voltage, the voltage is found as above at the first receiving station. The same formulae are used throughout for the various sub-stations, the load at each being taken as full load *minus* the loads of the stations already dealt with.

In this case the voltages were worked out twice, the first, assuming the station to be fed from the east line and the second, assuming the station to be fed from the west line. The voltage worked out on this basis served as a starting point for the calculation of the mains.

Taking each circuit independently the lighting mains were worked out by the following formula :—

Activity of one phase :—

$$W = \frac{E}{\sqrt{3}} \times C.$$

Activity of three phases :—

$$W = E \times C \sqrt{3}.$$

Hence $C = \frac{W}{E\sqrt{3}}$

Where W = Watts.
C = Amperes.
E = Volts.

From this formula was found the current in each circuit. The C R loss was then worked out in the usual manner, using a no. 9 wire to start with and finding by "trial and error" the smallest size wire required.

Road lighting.

Originally the road lighting consisted of 44 arc lamps and 180 incandescent lamps. The length of the roads lighted was 13 miles.

The arcs were placed along the main roads of which they lighted a length of three miles. The incandescent lamps lighted the remaining ten miles.

The arcs were of the totally enclosed type 2000 C. P. 8 amperes and designed for burning two in series, one pair of carbons lasting for 100 hours. The pillars are of the type and dimensions shown in plate no. XLV.

A great deal of trouble was experienced with the arc lamps; so much so that after being in service for one year it was resolved to get rid of them entirely and to replace them with incandescent lamps. This was done by removing the mechanism from the arc lamp and fixing in a three-way fitting in which were fixed three 32 candle power lamps.

The type of bracket for the incandescent lamps is shown in plate no. XLV.

All street lamps on each section are controlled from a single three-pole switch in the sub-station.

Notes and Criticisms on the low tension distribution.

The same trouble has been experienced with the low tension supports as with the high tension. As time went on, the state of the low tension system became so bad that the continuity of service was often interrupted and it became necessary to consider the remodelling of this system with iron telegraph poles. The defects of the old system were as follows :—

The low tension distribution wires were carried on *sal ballies.* The cross-arms were also of *sal* wood and secured to the pole by means of $\frac{5}{8}$-inch horse shoe bolts and nuts. This method was not a good one even under the best of conditions but with poles in the state the existing ones were in the arrangement was very unsatisfactory. In most cases the outer shell of the pole, to a depth of about 2 inches, was sapwood and it was simply impossible to keep the nuts strained up, with the result that the cross-arms often swung round and caused the wires to short circuit, thereby blowing the fuses in the sub-stations and sometimes damaging the transformers. This invariably happened in the dark and it was then extremely difficult to localize the seat of the trouble.

The method of fixing the neutral to the top of the pole was also unsatisfactory and a continual source of trouble, as a strong breeze sometimes blew the neutral wire and its fittings clean off the pole.

Again, at and under the ground line, every single pole was so far decayed that it was impossible to strain the wires up as they should be. This also, in a breeze, often caused "shorts" and burning out of transformers.

The supports of the remodelled low tension distribution system will consist of steel poles of the Hamilton type (B. C. D. sections), similar in all respects to the high tension poles which are being used on the re-construction of the high tension lines. These poles are being made in strict conformity with the Government of India specification (Telegraph department). Plate no. XLV shows a standard low tension pole fitted with a street light fitting. The lamps used will be of the metallic filament type only. Plate no. XLVII shows a switch pole which has been designed to enable sub-stations to be paralleled or run independently as may be required from time to time. The average spacing of the low tension poles will be kept at 150 feet approximately and a lamp will be fixed to each pole. On the main roads lamps of 100 candle power will be used. On the less important roads 50 candle power, and on the by-roads 25 candle power lamps only, will be used. Plate no. XLVIII shows a plan of the new type of distribution pole, which consists of a C. D. E. Hamilton pole with insulators arranged as shown in the plate.

The formula used in working out the voltage drop due to inductance is quite correct but the method of treating the case was somewhat out of date. Modern transmission engineers would not use it. A better formula would be that which gives the inductance of the line per mile as follows :—

$$L = (80\cdot5 + 740 \log \frac{D}{R}) (10)^6$$

Where D = distance between centres of wires.
R = radius of each wire.

In running the low tension distribution mains in Mussoorie a mistake was made in following the actual run of the roads, which, owing to the formation of the hill, zigzag considerably. There has been a great deal of copper wasted in doing this, as in many places "short cuts" could have been taken across "*nallahs*" instead of following the actual outline of the road. This is shown in plate no. XLVI which shows clearly what has been done. In figure A it will be seen that all 7 wires follow the many windings of the roads in order to get a sufficient number of lamps to give a good distribution of light. Had the wires been run as shown in figure B the result would have been a considerable saving in copper as the tappings taken back need only have been wire of small section.

The idea of using arc lamps for lighting was not good. Owing to the numerous bends in the road it was impossible to place the arcs so as to get an even distribution of light. The result of this was that one corner of the road would be brilliantly lighted and the next would appear to be in pitch darkness. Apart from this the lamps supplied were not suitable for Indian monsoon conditions and were far from water-tight, the result being that during the rains the energizing coils became soaked and were continually burning out. Moths were greatly attracted by the light and a great many found their way inside the lamp casing; this also caused the mechanism to jam occasionally. In addition to the above troubles there was a serious defect in the manufacture of the lamp. A part of the mechanism of the lamp is a dash pot with a plunger. This plunger was made of gun metal and was electroplated. This electroplating used to scale off, thus causing the plunger to jam in the dash pot and a "hanging up" of the rest of the mechanism of the lamp.

SECTION NO. V.—PUMPING STATION.

Motors.

The specifications for the various parts of the pumping plant were as follows:—

1. The exact number of motors required is not yet decided upon, but there will be either two of 150 H. P. each or four of 75 H. P. each, according as one or two lifts are adopted.

2. The motors to be of the induction type, to work on a 50 cycle circuit at a pressure of 6,000 volts. They will be used for driving the pumps for the water-works, so that all insulation must be non-absorbent and covered with moisture-proof compound.

3. Each motor to be provided with the usual starting resistance and short circuiting gear, and must start pumping without materially exceeding normal current limits.

4. The motors to be fitted with long bearings and suitable shafts, &c.

5. The power factor at full load should not be less than 0·87, and at three-quarter load not less than 0·81.

6. The temperature rise after 24 hours' run on full load should be stated in the annexed table.

7. The commercial efficiency should be filled in, in the annexed table.

GUARANTEED EFFICIENCIES.

	Full load.	¾ load.
150 H. P. Motor ...		
75 " " ...		

Pump house switch boards. 8. The switch boards for the pump house or houses, as the case may be, to consist of three marble panels, each fitted as follows :—

2 Motor panels each fitted with—

1 Triple pole high tension switch and fuses.
1 Voltmeter with transformer.
1 Ammeter „ „
1 Watt hour meter „

1 Lighting panel fitted with—

1 3 K. W. transformer.
1 Triple pole high tension switch and fuses.
1 „ low „ „

Pumps. 1. The total quantity of water to be pumped for the present is 180 gallons per minute; the total lift, including frictional and other losses, is 1,800 feet. Length of rising main is 4,500 feet.

2. It is not decided as yet whether one or two lifts are to be adopted. Tenderers must therefore quote separately for—

(a) Two pumps, each capable of the above output.
(b) Four pumps, each capable of lifting 180 gallons per minute to a height of 900 feet including frictional losses.

3. The pumps are to be driven by three-phase induction motors working on a 50 cycle circuit and at a pressure of 6,000 volts. They will have a normal full load rating of 150 H. P. each in case (a) and 75 H. P. each in case (b).

4. The pumps to be driven by ropes or suitable gearing to reduce the speed; and they must be fitted with all the necessary safety devices usual with pumps working under high pressure.

5. The pumps are intended to pump into the same rising main, but not to work together. Tenders must include all connections and fittings necessary as well as spares, tools, &c.

6. Attention has been drawn to the multi-stage or series centrifugal pump, and tenderers should quote separately for this type as well as for any other, the conditions of clause 2 remaining the same. These pumps will of course be driven direct by the motors.

7. Full details must be sent with the tenders as well as drawings showing the oundations necessary.

The specifications were distinctly vague and there was a lack of detail. The pumps were sub-contracted by the contractors and had up to the end of last season given endless trouble to all connected with them.

Description of the plant.

Motors. The motors supplied were not according to the specification drawn up by the Municipal electrical engineer.

They were made by the contractors and are of their standard three-phase induction "open" type with an output of 150 H. P., 380 volts, 50 periods and run at a speed of 750 R. P. M. (see plate no. XLIX and photo no. XII). The frame is circular in shape and is made of cast iron with feet cast on to it for bolting to bed-plate, bored and faced to take the stator stampings. The shaft is of mild steel with oil throwers to prevent the oil creeping into the rotor windings, and is carried on three cast iron pedestal bearings fitted with bushes, lined with white metal and lubricated by oil rings. The whole is mounted on a cast iron bed-plate of heavy section, which rests on slide rails provided with dogs for tightening the ropes when necessary. The stator core is built up of laminations of charcoal iron stamped and assembled in a cast iron frame. The coils are of the former type placed in semi-closed tunnels insulated with mica. The rotor is provided with 3 phosphor bronze slip-rings, fixed to, and insulated from, the shaft. The motors are controlled by an oil cooled three-phase starter.

Pumps. The pumps, two in number (see plate no. L and photo no. XIII) are of the Worthington horizontal, triplex type, with 3 single acting plungers 6 inches in diameter having a stroke of 15 inches arranged for driving by a double reduction of gearing. These pumps are capable of delivering 180 gallons per minute against a total head of 1,800 feet including suction and friction, when running at a speed of 44 R. P. M. The crankshaft is of mild steel having three cranks disposed at equal angles of 120 degrees and is extended at one end to receive the second reduction spur wheel.

The connecting rods are of mild steel and of the marine type. The crossheads are also of the marine type and are fitted with renewable slippers having large wearing surfaces.

The guides are of cast iron, secured to the bed-plate of the pump, which is of heavy section cast iron and weighs approximately 5 tons. The main bearings and bed-plate are cast in one, the bearings being lined with gun-metal. The pump barrels are cast iron fitted with deep stuffing boxes. The glands and necks are lined with gun-metal. The glands are secured by steel studs and nuts. The valve boxes are of cast iron, fitted with covers to give free access to the valves. The valves and valve seats are of gun-metal and the plungers are of cast iron fitted with gun-metal sleeves. The teeth of the gearing of the first reduction, as originally supplied, was of the involute form and that of the second reduction was of the machine-moulded double helical type. The pinion and countershafts are of mild steel and carried on bearings cast on the bed-plate, and are lined with gun-metal. The pumps are lubricated by means of oil rings on the pinion shaft and grease cups on the counter and crankshafts.

Drive The pumps are driven by six cotton ropes from the motor. The drive is 20 feet long. The pulleys are of cast iron and of equal diameter, viz. 28 inches.

Switch board. The switch board consists of three panels. One for each pumping, unit and one for the lighting of the pumping station.

The following instruments are mounted on each of the pump panels :—

One high tension voltmeter reading 0 to 7,000 volts.

One „ „ ammeter „ 0 to 20 amperes.

One balanced load Watt meter.

One high tension 3-pole oil switch.

These, with the necessary transformers, high tension fuses, &c., are shown in the diagram of connections in plate no. LI. The station is lighted by a 3-phase, 3-kilowatt, 6300/380 volt transformer with the neutral brought out giving 220 volts for lighting, and on the station panel is mounted a high tension oil switch and a 3-pole quick break low tension switch.

Transformers. Each pump set is fed through a 125 K. W. 3-phase, 6,300/380 volt oil cooled transformer (see plate no. LII). These are connected to the high tension supply by means of lead-covered, 3-cored paper-insulated cables, which run in 3-inch ducts through the pump house floor. Plate no. LIII shows the low tension switch board and motor connections.

TROUBLES WITH THE PUMPING PLANT.

The first serious break-down with the pumps occurred in November 1909 and was due to the crankshaft of no. 1 set breaking and smashing the entire bed-plate. The cause of this was a flaw in one of the crank webs. To repair the damage the whole of that set had to be dismantled, and the bed-plate lifted off its foundations and patched at the fractures with $\frac{3}{4}$-inch steel plate both inside and outside. These repairs were carried out by the contractors as the plant had not, at that date, been taken over by the Board's engineers. There is no doubt that, apart from flaws in the metal, the webs of these cranks are too light and at an early date new cranks with more metal in the webs must be put in. In May 1912 the crank of this same pump set developed a fracture at exactly the same place but fortunately this was discovered in time to prevent another complete smashing up of this set. Had this happened it would have meant the ordering of a new bed-plate.

The defects noticed from time to time in the working of these pumps and the remedies applied are stated at length in Appendix D.

A weak point about the design of these pumps is the rope drive. To begin with *there is no object in having a rope drive at all* as the motor and pinion shaft run at exactly the same speed. Hence there is no reason why they should not be *direct geared* through a flexible coupling without any intermediate drive. The bad points about the rope drive are :—

(1) The drive is too short (20 feet).
(2) The speed of the motor is too high (750 R. P. M.).
(3) The diameter of the ropes is too great ($1\frac{1}{4}$ inches).
(4) The diameter of the pulleys is too small (28 inches).

As a result of the above state of affairs, ropes were continually breaking; so when the design of the gearing was gone into by the Board's engineers they also carefully considered the design of the rope drive. The result of their calculations was given in a report to the Board, the gist of which was as follows :—

It is well known in connection with the rope drives that the diameter of the pulley should be at least 30 times the diameter of the rope. Now the diameter of the ropes is $1\frac{1}{4}$ inches and of the pulley 28 inches; this shows *at once* that the ratio of the ropes to the pulley is hopelessly out.

In order to get as near as possible to the proper ratio it was decided to replace the existing 6 *grooved* 28-inch diameter pulleys with pulleys of the same diameter with *10 grooves* suitable for 1-inch ropes. It should here be mentioned that it was impossible to increase the size of the pulleys owing to the construction of both the motor and the pump bed-plates. The following figures show how the size of the ropes was arrived at :—

Diameter of rope $= \frac{\text{Dia. of pulley}}{30} = \frac{28}{30} = 0{\cdot}933$ inches.

Velocity of rope $\doteq \frac{\pi\, d \times \text{speed}}{12} =$

$= \frac{3{\cdot}1416 \times 28 \times 750}{12} = 5{,}500$ ft. per minute.

$H = PV \div 33{,}000\, K.$

Where H = horse power transmitted by one rope.

P = a constant relative to the girth of the rope and in this case = 94.

V = Velocity in feet per minute and in this case = 5,500.

K = Constant dependant on the proportion of the arc of contact of the rope with the pulley and in this case = 1.

Therefore $H = \frac{94 \times 5{,}500}{33{,}000 \times 1} =$ say 16 H. P.

Number of ropes required $= \frac{150}{16} = 9 \cdot 4$, say 10.

A copy of the report drawn up by the Board's engineers on the design of the various parts of the pumping plant giving trouble was sent to the Electrical Inspector to Government for criticism. He promptly replied that he entirely agreed with the report and recommended that the Board's engineers' suggestions for the remedy of these troubles should be carried out.

On receipt of this reply pulleys were ordered with ten 1-inch grooves instead of six 1¼-inch grooves. This alteration has also proved a success. A set of one-inch ropes has now been running for nearly a year and is still in good condition. Whereas with the original ropes, in one set two ropes broke after four days' running and the fracture was not at the splice.

After considering and acting on their engineers' advice the Board decided to ask the contractors to defray the expense of the alterations which they promptly refused to do and at the same time denied that the design of the pumps was faulty. That the original design of the pump gearing and rope drive was defective is proved by the fact that since the re-designing of the parts in question little or no trouble has been experienced.

In consequence of the frequent break-downs at the pumping station, the pumps have been severely criticised by engineer critics from time to time and many suggestions have been made regarding them. In most of these suggestions centrifugal pumps have been strong favourites and if the quantity of water to be dealt with had been thousands of gallons per minute, instead of hundreds, this type of pump would have been the most suitable. But as the quantity of water is very small compared with the lift there can be no doubt that the ram type of pump is the most efficient for this service.

A mistake was made in not asking the pump makers to supply more spares. It is true that in the specification spares were mentioned but that was about all. The makers supplied the same as they would to a similar plant at home, but what applies to spares for a home plant does not apply to a plant in India more especially in out-of-the-way stations in the hills. In the "spares" section of the specification it would not have been too much to call for *complete sets* of all moving parts of the pump, with the exception perhaps of the plungers, guides and connecting rods. Further, in view of the complicated machinery at the pump house, it would have been wise to have provided a workshop equipped with machine tools capable of dealing with any ordinary break-down that might happen, and at all events if funds would not run to this the workshop at the power house ought to have been properly equipped with up-to-date machinery.

CHAPTER IV.

WATER WORKS.

Water supply.

The supply of water is obtained from three springs situated on the west slope of Herne Hill beyond the Happy Valley (see plate no. I). The positions of the springs with regard to the pumping station are shown on plate no. XIV.

From discharges taken during the three years 1908 to 1910 it was found that the supply available in gallons per minute was—

Spring no.	1,	maximum	44,	minimum	18.
„	2	„	65	„	25
„	3	„	95	„	73
Total		„	204	„	116

The total minimum supply is therefore 167,040 gallons per day which is equivalent to 9½ gallons per head of the population as determined by the summer census of 1910.

The water of all three springs is of excellent quality as far as freedom from organic matter and bacteria is concerned, but it is undoubtedly hard. The following is an analysis of a sample taken from the collecting reservoir at the pumping station in November 1909:—

Total solid parts per 100,000	72
Chlorine parts per 100,000	1·0
Total hardness in grains per gallon	52·5
Fixed hardness per gallon	31·5
Free ammonia in parts per 100,000	0·005
Albuminoid ammonia „ „	0·001
Nitrites and nitrates „ „	*Nil.*

The spring water is impounded in small masonry tanks (plate no. XV, figure 1) at points where it issues from the hillsides and is completely covered in to protect it from surface contamination. As a further precaution against contamination by percolation the whole of the drainage area on the hillsides above the springs, amounting to 83 acres of forest and grass land, has been acquired and the grazing of cattle within it prohibited. It is, however, doubtful whether this was really necessary as the source of water supply in the springs is deep seated. This is evidenced by the fact that in 1909—1910 the *minimum* discharges from the springs were recorded in July though in that year the rains broke early and were abnormally heavy; thirty inches being recorded in the vicinity between the 1st of June and the middle of July. The spring water is at all times perfectly clear. No arrangements for filtration have been provided and in the circumstances none seem necessary.

Near spring no. 2 a small collecting reservoir (plate no. XV, figure 2) of similar design to the impounding tanks has been constructed and connected to them by means of pipes. From this reservoir the combined supply is conveyed to another reservoir at the pumping station. The impounding and collecting tanks are constructed of uncoursed rubble masonry on a slab of concrete 1½ feet thick and are roofed over with brick arching. The mortar used is composed of 1 part stone lime, 1½ parts *surkhi* and ½ part sharp *bajri*. The interior of the tank is plastered with a mixture of 1 part Portland cement, 1 part *kankar* lime and 3 parts *bajri*. A small door of galvanized sheet iron, hung on angle steel framing, is provided at the lower end of each tank and a strainer of wove wire is fitted in grooves in the upper end wall where the spring discharges into the tank. When it is necessary to empty the tank for cleaning or repairs the spring can be diverted into a pipe leading through the side wall by removing the wire strainer and replacing it by wooden planks.

The pipes from the springs to the collecting reservoir and from the latter to the reservoir at the pumping station are of galvanized lapwelded mild steel, the ends being turned up and joined together by means of split flanges of cast steel and fibre washers. It was at first proposed to bring the water from the springs to the pumping station in masonry ducts but this idea was subsequently abandoned on sanitary grounds and on the score of expense. It may be mentioned here that mild steel pipes are admirably adapted for hill work owing to the facility with which they can be bent cold to any angle up to 20 to 25 degrees from the straight. This is a great advantage in laying pipes along the contour of a hill and obviates, to a great extent, the necessity for using specially made bends. The pipes are bent without filling them with sand, generally either in the fork of a tree or, if the ground is hard, in the trench itself round the convex face of the curve. It may also be noted that such pipes are bent more easily in summer than in winter particularly if their temperature is raised by placing them in the sun.

The following are the discharge capacities of these pipe lines as calculated from Box's formula $H = \frac{G^2 L}{(3\,d)\,5}$.

(i) Spring no. 1 to small collecting tank—

Length of pipe line	320 feet.
Head	93 „
Diameter of pipe	2 inches.
Discharge capacity	82 gallons per minute.

(ii) Spring no. 2 to small collecting tank—

Length of pipe line	90 feet.
Head	7 „
Diameter of pipe...	3 inches.
Discharge capacity	117 gallons per minute.

(iii) Spring no. 3 to small collecting tank—

Length of pipe line	1,012 feet.
Head	90 „
Diameter of pipe...	3 inches.
Discharge capacity	125 gallons per minute.

(iv) Small collecting tank to collecting reservoir at pumping station—

Length of pipe line	1,926 feet.
Head	33 „
Diameter of pipe	5 inches.
Discharge capacity	198 gallons per minute.

This is almost equal to the maximum combined discharge of the springs which, however, occurs at a time of the year when the consumption is at its minimum.

Pumping station. The pumping station is situated at the bottom of the valley between Abbey Hill and Herne Hill about 3 miles from the Library and a mile below the "Old Brewery" from which it is reached by means of a service road 8 feet wide and an average gradient of 1 in 10.

The station (plate no. XV) comprises the following buildings:—

1. Pump house.
2. Drivers' quarters.
3. Menials' quarters.
4. Collecting reservoir, and
5. Inspecting officer's room and store.

The pump house (plate no. XVI), in which are erected two sets of pumps, motors and transformers, measures 50 feet × 24 feet inside and has a tower 7 feet × 7 feet in one corner in which are located the switch board apparatus and electric wire connections. The high tension lines are led into the building through apertures in the walls of this tower.

The class of work in the pump house is generally similar to that in the power house.

To enable any part of the plant to be lifted and handled for repairs, rolled steel joists, on which differential pulley blocks run in the ordinary way, have been fixed across the building at suitable intervals at a height of 14 feet above the floor. It would have been a better arrangement if an overhead travelling crane had been provided. There are two sets of motor-driven pumps—one for use, the other as a stand-by. Both deliver into the same rising main. The motors have a full-load rating of 150 B. H. P. and are connected with the pumps by means of a rope drive and gearing which reduces the motor speed of 750 revolutions per minute to 45 at the pump crank shaft. The pumps are of the Worthington three-throw type with barrels 6 inches in diameter and a length of stroke of 15 inches. They have been designed to deliver 180 gallons per minute through a 5-inch rising main 4,500 feet long, against a head (including frictional and other losses) of 1,800 feet. The actual vertical lift is 1,722 feet, including the suction lift of 11½ feet, whilst, owing to a subsequent change in the site of the pumping station, the length of the rising main has been increased to 6,000 feet. With a speed of 45 strokes per minute the theoretical delivery of the pumps is 207 gallons so that the allowance made for slip on an effective delivery of 180 gallons per minute is practically 13 per cent.

The following are the results of actual tests made in 1909 :—

Pump set no. 1.

Duration of test	1 hour.
Speed of pump	44 strokes per minute.
Delivery per minute by meter	183·9 gallons.
Percentage of slip	9·13 gallons.

Pump set no. 2.

Duration of test...	...	...	...	1 hour.
Speed of pump ...	...	...	...	42·25 strokes per minute.
Delivery per minute by meter		...	...	190·76 gallons.
Percentage of slip	...	...	...	8·35 gallons.

Outside the pump house a sluice valve is fitted on the rising main and, below it, a dead weight relief safety valve 2½ inches in diameter with a 5-inch pipe leading from it (the safety valve) into the collecting reservoir.

As it has been found impracticable to start the motors against the inertia of the full column of water in the rising main, the sluice valve is shut down to cut off the pressure to begin with and pumping is commenced against the relief valve, weighted up to the load the motors will take at starting. As the motors take up the load the sluice valve is gradually opened to its full extent, whilst the relief valve is at the same time proportionately weighted up. In this way the pumps start by pumping back into the collecting reservoir through the relief valve pipe and continue to do so in gradually decreasing quantity for several minutes until the motors take up the full load, when the flow through the relief valve ceases.

The pumps and motors are set on foundations of cement concrete 4 feet thick to which the cast iron bed plates are secured by holding-down bolts. The vibration in the pumps was at first considerable and was communicated to the walls of the pump house to such an extent that fears were entertained that it might eventually affect the stability of the building. To counteract this the pump foundations were isolated by making a channel 6 inches wide and 1½ feet deep all round them and filling it with sand. This greatly reduced the vibration in the walls whilst on the other hand the pumps themselves ran much more smoothly after the new gearing had been in use for some time. The pump bed plates weigh 4 tons each.

The collecting reservoir (plate no. XVI) adjoins the pump house and measures 48 feet × 25 feet with a depth of 8 feet to full supply level.

The walls are constructed of rubble masonry laid in mortar composed of 1 part stone lime, 1½ parts *surkhi* and ½ part *bajri*. The concrete in the floor and foundations is composed of 100 parts stone ballast and 45 parts mortar similar to that used for the masonry. The interior, both floor and walls, up to 1 foot above full supply level is plastered with mortar consisting of 1 part *kankar* lime and 1 part *bajri* finished off with a thin coating of Portland cement. The exterior is plastered with a mixture of stone lime, *surkhi* and *bajri*. The roofing is similar to that of the pump house, i. e. galvanized corrugated iron on a bar iron framing. Scour and overflow pipes 5 inches in diameter are provided and the suction pipes which have rose heads and flap valves at their lower ends are of the same diameter.

The subsidiary buildings (plate no. XVII) comprise two sets of quarters for the native drivers, a block of four units for cleaners and oilers, a block consisting of a room with a bath room for inspecting officers and a store godown. All these buildings are constructed of ordinary rubble masonry with roofing of galvanized corrugated iron on *chir* wood framing.

As has been stated above, the rising main (plate no. XVIII) has a length of 6,000 feet and a vertical rise of 1710·5 feet from the pumps to the reservoir on the top of Vincent's Hill. The static pressure on the pipes at the pump house is therefore 1710·5 × ·434 = 742·35 lbs. per square inch. The line runs for the most part obliquely up the hillside and follows, as closely as the nature of the ground will permit, a straight line drawn between the terminal points. The pipes have been buried to a minimum depth of 1 foot below ground level wherever this was practicable. At six points where the line crosses small watercourses, the pipes are carried on masonry pillars and at several places where the line runs straight up a steep slope it has been found necessary to build cross bars of dry stone masonry at intervals of about 20 feet to prevent the pipe trench from being scoured out during the rains. Two thrust blocks have been given at the pump house, viz. one at each of the right angled horizontal bends which carry the pipe line, as it leaves the pumps, clear of the building. These thrust blocks are constructed of cement concrete and the pipes are secured to them by means of iron collars and holding down bolts. A third thrust block is provided about half way up the line where, after crossing a *nala*, it bends sharply up a very steep hillside. At the upper end of the line, where the pipes are carried up a cliff 70 feet in height, thrust blocks have been given both at the bottom of the cliff and at the top just outside the reservoir. Two non-return valves are provided on the line at about one-third and two-thirds of the distance from either end. A Kent's meter is fixed at the upper end.

Throughout the distribution system, including the pipes from the springs to the pumping station, all pipes between 2½ inches and 5 inches in diameter are of the same type and material as those in the rising main. The latter are 5 inches in diameter and ·232 feet thick. Details of the joints are given on plate no. XX, figure 1. These joints were found to be quite satisfactory everywhere except on the rising main where pressures are unusually great. They gave trouble particularly in places where it was not found possible to steady the pipes by burying them in the ground. The flanges which were of cast iron were found to be too weak and they usually failed by snapping across the bolt holes where the two half flanges overlap. This generally occurred when the bolts were being tightened up during construction, but it was no infrequent occurrence to find similar failures along the line after the pipes had been put into use. A supply of cast steel flanges of the design shown in figure 2 of plate no. XX was subsequently obtained and these have stood the strain without a single case of failure. During the first year's working one pipe burst along the lap weld, whilst several gave way at the angle formed by the turned up end. These failures were evidently due to defects in the manufacture of the pipes.

The old Mussoorie water supply (plate no. XXI) installed in 1893 was obtained mainly by pumping from the Mackinnon spring but was supplemented by a number of smaller springs in different parts of the station from which the water was led in pipes to suitable points where iron delivery tanks of from 400 to 800 gallons capacity were erected. The supply from the Mackinnon spring, amounting at its minimum to about 40 gallons per minute, was pumped up from the pumping station, on the south side of the hill below the Library, into a reservoir of 72,000 gallons capacity, situated on the spur behind the Library. The pumps which are now only retained for use as a stand-by in case of a break-down in the more modern plant, are steam-driven and of the Worthington type. The lift is 600 feet and the diameter of the main 3 inches. From the reservoir a 2-inch pipe line runs westward along the Mall to the entrance to the tennis grounds at the Happy Valley, whilst another line varying from 3 inches to 1 inch in diameter goes eastward along the Mall to the foot of Club Hill and thence along the Masonic road to its junction with Airfield road. Both these lines, as well as the reservoir which feeds them, have been utilised in the new distribution system. The following springs which give small supplies by gravitation have also, for the present, been retained for service:—

(1) *Chalmer Khud Spring,* (plate no. XXI). The supply from this amounting to 5 gallons per minute is carried along the hillside below the Mall eastward to Hampton Court. The line is 7,500 feet long with a fall of 19 feet and the bore of the pipe is 2 inches. The piping is mostly of black iron laid many years ago and is in very indifferent order. It will be necessary before long to abandon this line, as under existing conditions it will not be worth while to renew the piping. The service tanks at the springs, as well as at Shawfield road and Hampton Court, will, however, be retained, the last two being connected with the new distribution system.

(2) *Khattapani Spring,* (plate no. XXI). This spring yields a minimum of 4 gallons per minute and is served by a pipe line about 1½ miles in length which discharges into two 2,500-gallon iron tanks erected on the north slope of the hill below the Mall near Garden Reach. There is very little pressure in this line and the pipes (3½ inches in bore) are of diverse kinds. Much of the original piping made of galvanised sheet iron and put down over 30 years ago has since been renewed. The maintenance of the line under existing conditions is a matter of doubtful utility but it is retained as it would be useful in case of a break-down.

(3) *Brooklands Spring,* (plate no. XXI). The supply from this spring amounting at a minimum to about 6 gallons per minute is carried for about half a mile in a 2-inch pipe and delivered into three iron service tanks each of 800 gallons capacity erected at the upper end of Barlowganj bazar. This pipe line is in good serviceable condition and as the water is of excellent quality the system is being retained for the supply of the bazar. Any shortage in supply may be made up by tapping the new main which runs close by.

The new distribution system is fed by gravity from two masonry service reservoirs (plate no. XIX) constructed at Craig Top, the highest point of Vincent's Hill. Each reservoir measures 40 feet × 25 feet inside and holds 50,000 gallons. Owing to the nature of the site it was found necessary to place them at different levels, the floor of reservoir no. 1 into which the rising main discharges being 8½ feet higher than the floor of no. 2 from which the 4½-inch service main takes off. These reservoirs are similar in design and construction to the collecting reservoir at the pumping station and are connected by a 5-inch pipe with a sluice valve to regulate the discharge from the upper into the lower.

The pipes used for distribution are of mild steel, lap welded and galvanised. In all pipes from 4½-inch to 2½-inch bore the joints are similar to those already described for the rising main. In those from 2-inch to 1½-inch bore the pipes have flanges screwed on to their ends. These flanges are faced and grooved and bolted together by four bolts of ⅝-inch diameter, red fibre washers being used to make the joints water-tight. Pipes of 1-inch bore and under have the ordinary screw and socket joints. A 4½-inch main runs from the lower reservoir on Vincent's Hill to the existing reservoir of 30,000 gallons capacity on Camel's Back Hill.

A branch of this line which takes off near its head goes off towards the west, along Blucher's Hill to the foot of Abbey Hill. At upper Mussoorie bazar another branch goes off in a northerly direction, via Tullamore road and Happy Valley, to the foot of Herne Hill. Further on a short branch pipe 3½ inches in bore connects the 4½-inch main with the reservoir near the Library from which the old pipe lines running west along the Mall are fed. From the former of these a 1-inch pipe is taken off to flush the sewage main which conveys the greater part of the night soil of Mussoorie to the trenching grounds at Bhilaru.

From the reservoir on Camel's Back a 3½-inch main runs to a point on the Mall below the Himalaya Club, whence the line is continued by a 2½-inch pipe to the Landour bazar. Near the end of the 3½-inch main a branch line is taken off and after crossing Club Hill goes on to Barlowganj, following for the most part the Rajpur-Mussoorie bridle road. Plans and sections of the main and branch lines are given in plates nos. XXI, XXII and XXIII.

The standposts (plate no. XXIV) are erected on platforms of brick-work and are each provided with two Kennedy's patent, non-concussion, self-closing, brass taps, ½ an inch in diameter. Under one of the taps there is a small sloping platform of masonry on which the *bhisti* places his water bag while it is being filled. The other tap is used for filling buckets or other water vessels. The break-pressure tanks which are also used as service tanks are of galvanised iron, 4 feet cube, having a capacity of 400 gallons. Each tank is furnished with a floating ball valve to regulate the supply, and two delivery galvanised iron taps 1-inch in diameter. Masonry platforms are provided similar to those for the standposts. There are in all 19 standposts and 5 break-pressure service tanks which, together with the 9 old standposts and 6 old service tanks connected to the new distribution system, give 39 points of delivery to the public or practically one point to every 450 of the total summer population of 17,420. With a view to stimulating the demand for house connections it was considered inadvisable to be over-liberal in the provision of public standposts at the outset and this has proved to be sound policy inasmuch as about 140 metred house connections, from which the Board is deriving a considerable income, have already been installed.

There is nothing on record to show that detailed surveys and calculations were ever made for the water distribution before the pipes and fittings were ordered from England. By the end of 1906 practically all the pipes and fittings had arrived and the only information available as to the laying of them was contained in an eight inch to the mile map of Mussoorie on which the rising and service mains had been marked roughly in blue lines. Any rough calculations that may have been made for the lengths and sizes of the pipes appear to have been based on this map and on the assumption that the quantity of water to be distributed was 180 gallons per minute, i.e. the delivery specified for the pumps at the pumping station. The result of this want of full and correct data at the outset was that the materials on hand had to be utilised in the best manner possible, and additional material to a considerable extent had eventually to be procured.

Calculations of the discharges of the main and branch pipe lines based on the pump delivery of 180 gallons per minute are given in Appendix E. In these calculations the population to be served has been taken at 18,000.

This gives an allowance of $\frac{1 \times 60 \times 12}{100} = 7 \cdot 2$ gallons per head of population per diem assuming a draw of 12 hours. This allowance may seem small for a large town, but it must be remembered that there are no industries in the place which tax the resources of the water-supply. The breweries that do exist have their own pipe lines from independent springs and are therefore not dependent on the water works system. The consumption of water in the hills for domestic purposes is also naturally lower than in the plains of India.

In the new distribution system there are 5 break-pressure reservoirs of 400 gallons each and 19 standposts. These reservoirs are each furnished with two delivery taps of 1 inch diameter and are themselves used as service tanks. Should the supply ever fall short of the demand at or near the terminal points by reason of an excessive draw on the pipes the number of service tanks can always be increased.

According to the census taken during the season of 1910 the population of Mussoorie within Municipal limits was 17,420 of whom 3,976 were Europeans or Eurasians and 13,444 Indians.

The census area, however, included a number of outlying inhabited sites beyond the scope of the distribution system. As has been already mentioned, the minimum yield from the 3 springs that have been taken up is 116 gallons per minute or 167,040 gallons per day. This amount can be pumped up in 15½ hours. During the two seasons the new water supply has been in service the maximum consumption in one day has not exceeded 120,000 gallons whilst the maximum daily average for any one month was 86,476 gallons. There is therefore an ample margin for future expansion.

The scheme as originally drawn up provided for an extension of the water supply to the Landour Cantonment, but this part of the project was, as has been mentioned in a previous chapter, subsequently omitted from the revised estimate, owing to disagreement between the Municipal and Military authorities. Later on negotiations were resumed and in the beginning of 1910 a 1-inch pipe line was laid by the Board as a temporary arrangement from the end of the 2½-inch main to the Supply and Transport office, close to the Soldier's Home above the Landour bazar, in order to supplement the Cantonment supply from springs which were found to be insufficient to meet the requirement during the season. Under this arrangement (which was renewed for the season of 1911) the Board provided and maintained the pipe line and charged for the water consumed at the rate of Rs. 2-8-0 per 1,000 gallons. From 15,000 to 20,000 gallons per day can be spared for this purpose and can be delivered into a reservoir on some suitable site near the Supply and Transport office whence it can be pumped up to the top of the Landour hill, a height of about 600 feet.

APPENDICES.

APPENDIX A.

Items.	Amount.	Total.	Remarks.
	Rs.	Rs.	
1.—*Head Works*—			
Dam	3,956		
Intake	1,350		
Reservoir	15,194		
Offtake and penstock chambers	2,395		
Buildings for housing men in charge ..	1,096		
Retaining walls	2,317		
Service road...	1,974		
		28,282	
2.—*Power pipe line*—			
Power pipes and fittings delivered at Bombay ..	1,35,370		
Railway freight and carriage to site ..	14,384		
Erection and fitting	9,383		
Construction of pipe track	17,168		
Sal sleepers under pipes..	3,952		
Bridging stream	4,588		
Tools and plant	1,205		
		1,86,050	
3.—*Generating Station*—			
(a) Power House—			
Plant and apparatus	56,790		
Overhead crane	2,280		
Erection of plant	3,290		
Clearing site, drainage and retaining walls ..	6,640		
Power house building	18,249		
Superintendent's quarters	8,408		
Drivers' quarters	2,192		
Cleaners' ,, ...	1,122		
Service road	20,085		
Temporary buildings	4,573		
(b) Workshops—			
Plant and apparatus	6,000		
Building	5,229		
Retaining walls	767		
		1,35,685	
4.—*Transformer stations*—			
Plant and apparatus	26,400		
Erection of ,, ...	4,339		
Buildings	15,415		
Service roads, retaining walls, fencing, &c. ..	2,473		
		48,627	
5.—*Primary mains*—			
Copper wire	13,305		
Insulators	2,970		
Lighting arrestors	4,470		
Barbed wire	1,804		
Sal ballis	26,314		
Sal cross arms	3,012		
Bolts and nuts, stays, &c.	3,232		
Digging holes and building pushtas ..	2,413		
Erection	14,740		
		72,260	
6.—*Secondary Mains.*—			
Copper wire	40,077		
Insulators	2,565		
Lighting arrestors	8,447		
Sal ballis	1,364		
Sal cross arms	423		
Telegraph posts	16,066		
Bolts and nuts, stays, &c.	3,698		
Digging holes, &c.	647		
Erection	7,065		
		80,542	
7.—*Road lighting.*—			
Arc lamps	3,065		
Pillars for lamps	9,452		
Incandescent lamps	1,627		
Copper wire	144		
Insulators	167		
Erection	2,757		
		17,212	
8.—*Telephone Equipment*—			
Telephone instruments and fittings ..	4,031		
Copper wire..	635		
Erection	545		
		5,211	
9.—*Water supply.*—			
(a) Springs and intake—			
Service road to springs	1,395		
Impounding tanks	1,032		
Pipe lines from springs to pumping station ..	8,359		
Total ..	10,786		

Items.	Amount.	Total.	Remarks.
(b) Pumping station—	Rs.	Rs.	
Plant and apparatus	41,708		
Erection	2,791		
Pump house building	6,268		
Collecting reservoir	5,039		
Drivers' quarters	1,692		
Menials' „	1,427		
Inspecting officer's quarters and store room ..	1,625		
Temporary buildings	456		
Clearing site	1,427		
Retaining walls and drains	3,254		
Service road	1,661		
Total ..	67,348		
(c) Rising main—			
Pipes and fittings	17,834		
Pipe laying	2,059		
Total ..	19,893		
(d) Service reservoir	15,099		
(e) Distribution mains, &c.—			
Pipes and fittings	29,378		
Pipe laying	6,289		
Stand posts and delivery tanks	3,576		
Water meter	1,149		
Total ..	40,392		
Total for water-supply ..	..	1,53,518	
10.—*Store and tools*—	..	10,041	
11.—*Freight charges*—			
Railway freight from Bombay	13,749		
Landing and forwarding charges	3,490		
Customs duty	1,466		
Carriage from Dehra	15,267		
		33,992	
12.—*Establishment*	..	61,714	
13.—*Compensation for land, &c.*—			
Purchase of land at Murray Springs ..	25,098		
Compensation for other land	8,225		
Compensation for trees	6,376		
		39,699	
14.—*Stock*—	..	27,030	
15.—*Contingent charges*.—			
Preliminary charges	18,296		
Salaries of Contractor's Engineers	39,762		
Office contingencies	4,919		
		62,977	
GRAND TOTAL ..	..	9,62,840	

APPENDIX B.

EACH governor consists of the following principal parts (see photo no. I and plate no. XXXIII):—

1. Receiver (1) ... } with necessary pipe connections.
2. Pressure tank (2) ... } with necessary pipe connections.
3. Power pump (3,10) driven by pulley (4).
4. Hydraulic cylinder (62).
5. Balanced regulating valve (14).
6. Centrifugal governor head (30,38,41).
7. Anti-racing mechanism consisting of:—Lever (110), dash pot (43), valve stem rack (74) and pinion (47).

The pressure tank (2) containing air and oil in nearly equal volumes under a pressure of from 100 to 200 lbs. per square inch serves as a source of energy for the hydraulic cylinder of the governor. The smaller compartment (1) serves as a receiver of oil exhausted from the hydraulic cylinder.

The function of the pump is to remove the oil from the receiver as fast as it accumulates and return it to the pressure tank. In so doing all the energy given by the pressure tank to the hydraulic cylinder is restored to the former. But it should be observed that the pump restores this energy at a constant and comparatively slow rate, while the hydraulic cylinder, when required, uses the energy from the tank very rapidly.

The oil from the pressure tank is supplied to the working cylinder (62) through the regulating valve (14) arranged to discharge or exhaust oil directly and rapidly into, or from, either end of the cylinder. This regulating valve (14) and the sleeve in which it travels are made of hardened steel and the valve is well balanced.

The connection between the centrifugal balls and the regulating valve (14) is a valve stem in two parts (53) connected by a screwed coupling (52) so arranged that the total length can be increased or diminished. The normal running speed of the governor may thereby be altered. This valve stem (53) terminates above, inside the top of the governor head in a very steep pitch screw. This screw may be turned in a nut which cannot rotate but which moves up and down with the flange to which the upper ends of the flat springs carrying the balls (30) are fastened.

The portion of the valve stem above the adjusting coupling (52) carries a pinion (47) which engages with a rack (74) normally held in a central position by means of a tension spring (48). The part of the valve stem containing the steep pitch screw, pinion and rack, is a portion of the anti-racing mechanism. Through the lever (110) reduced motion is transmitted to the dash pot piston rod (77) and thence through the dash pot itself to the spring centred rack (74). If the dash pot could be considered as rigid with its piston, every displacement of the piston rod rack (127) would result in a corresponding but reduced displacement of the small rack (74) and consequently in a rotation of the upper part of the valve stem. This, through the action of the steep pitch screw inside the governor head, would tend to raise or lower the valve.

The assumption just made that the dash pot and its piston form a rigid connection is not strictly true but it is nearly so for quick movement. The oil contained within the dash pot allows the piston to move slowly in either direction without great resistance. Therefore if the piston rod (127) makes a sudden outward movement, the valve stem (53) will be instantly depressed, but through the action of the tension spring (48), which is continually tending to bring the rack (74) back to its central position, the body of the dash pot will gradually move with respect to its piston until the small rack has come back to its central position. At the same time valve stem (53) will be moving up, bringing with it the valve.

That this anti-racing mechanism is an essential part of the governor will now be demonstrated. First assume that it did not exist and let there be a plain connection between the governor top and the regulating valve (14); that is to say let the valve stem (53) be of unchanging length. Now let the governor be attached to a water wheel running at normal speed. The regulating valve (14) would be in its mid-position and there would be no tendency for movement of the hydraulic piston. Then let a small load change occur. Instantly the centrifugal balls will move to throw the piston rod (127) out or in. The movement of this piston rod would continue as long as the speed was away from the normal or until the piston had travelled its full stroke. In a Pelton wheel installation, the speed might be away from the normal for several seconds and since the governor would make a complete stroke in 3 seconds or less it is clear that the nozzle would be deflected from and returned to its normal position long before the speed had come back to the normal. As a result the speed would not only come back to the normal but would go beyond it in the other direction reversing the displacement of valve (14) and causing the piston of the governor to over travel again in the opposite direction.

This action would be repeated indefinitely which, to say the least of it, would be objectionable.

Now consider the anti-racing mechanism in use under the same conditions. First the speed being normal the valve (14) will be in its mid-position and the governor will be perfectly quiet. When a change occurs the fly balls will move immediately causing valve (14) by the admission of oil to the cylinder (62) to move piston rod (127) in the proper direction to counteract the change of speed. In the very act of movement of the piston rod (127) the length of the valve stem (53) is altered through the dash pot connection which rotates this stem so that valve (14) is brought back to its normal position irrespective of the position of the centrifugal balls. That is to say the movement of piston rod (127) is stopped long before the speed of the water wheel has come back to the normal. If the dash pot (43) formed a rigid connection at the upper end of lever (110) the governor would be perfectly stable in the new position but the speed would not be normal. The actual position of affairs, however, is such that dash pot (43) forms only a temporary connection from the end of lever (110) and neither lengthens nor shortens the length of valve stem (53) permanently, because, as before stated tension spring (48) is constantly acting to pull rack (74) back to its central position and thereby bringing the valve stem (53) back to its normal length. The time required for the spring to do this depends entirely upon the resistance which the adjustable valve (40) offers to the flow of oil in the dash pot. If the opening in this valve is very slight the dash pot will give way to the spring very slowly and on the other hand, if the opening is large, rapidly. It is possible to adjust the valve(40) so that the time required for the valve stem to come back to its normal length after a movement of the governor piston rod is approximately the same as the time required for the water wheels to come back to their normal speed after a temporary deviation.

If there is any tendency for the governor to deflect the nozzle through a greater angle than is necessary and then oscillate several times after a variation in the load, it is because the dash pot is not quite sluggish enough in its action. The remedy is found by slightly closing valve (40) or by increasing the viscosity of the oil in the dash pot; on the other hand, if the governor does not deflect the nozzle far enough when a load change takes place and is slow in bringing the speed back to the normal it is advisable to open valve (40) slightly or thin the oil by adding kerosine.

When the clutch pin (84) is thrown in, the governor piston in cylinder (62) is rigidly connected to shaft (64). If the clutch pin is withdrawn, hand operation may be obtained by inserting hand lever (132) in the socket of governor rocking lever (131).

Parts of Governor.

No.	*Column.*			*Parts.*
1	A 3	..	..	Vacuum tank or receiver.
1	D 4	..	..	Ditto.
2	A 7	..	..	Pressure tank
2	D 6	..	..	Ditto

No.	*Column.*			*Parts.*
3	D 6	..	..	Pump cylinder.
4	E 5	..	..	Pump pulley.
6	B 5	..	..	Safety valve.
10	D 5	..	..	Pump box.
11	E 5	..	..	Throttle valve.
14	E 6	..	..	Regulating valve.
20	E 4	..	..	Governor table.
21	B 4	..	..	Hand lever.
30	C 2	..	..	Governor ball.
33	F 4	..	..	Safety lever spring.
36	D 1	..	..	Oil cap in governor head.
38	E 1	..	..	Governor head tension spring.
39	E 2	..	..	Wing nut for tension spring.
40	C 2	..	..	Dash pot valve.
41	E 3	..	..	Governor head pulley.
42	B 3	..	..	Dash pot connection stud.
43	C 2	..	..	Dash pot.
47	F 3	..	..	Valve stem pinion.
48	B 3	..	..	Dash pot centering spring.
49	E 3	..	..	Nuts for rack-holder.
52	F 5	..	..	Valve stem connection.
53	B 4	..	..	Upper valve stem.
56	B 3	..	..	Parallel rod.
62	B 5	..	..	Main governor cylinder.
64	A 7	..	..	Governor terminal shaft.
70	E 7	..	..	Pressure check valve.
74	F 3	..	..	Centering rack in governor head.
77	C 3	..	..	Dash pot piston rod.
79	F 3	..	..	Rack holder.
84	A 8	..	..	Clutch handle.
87	E 1	..	..	Governor head collar.
88	B 3	..	..	Pressure gauge.
89	B 3	..	..	Vacuum gauge.
95	E 4	..	..	Safety lever.
103	E 8	..	..	Gauge cock.
105	C 2	..	..	Dash pot cover screw.
106	F 5	..	..	Valve stem adjusting gear.
110	B 3	..	..	Racing lever for dash pot.
114	C 2	..	..	Dash pot spring plunger.
117	E 1	..	..	Governor head lever.
126	F 2	..	..	Governor head spring stud.
127	B 7	..	..	Upper piston rod.
128	B 9	..	..	Lower piston rod.
130	A 8	..	..	Rocking lever disc.
132	E 9	..	..	Hand lever.
133	B 10	..	..	Piston rod guide.
134	D 4	..	..	Pump crank shaft.
135	E 3	..	..	Pump pulley shaft.
136	A 5	..	..	Pump piston.
137	A 6	..	..	Pump leather cups.
138	A 6	..	..	Pump piston end washer.
139	E 5	..	..	Pressure valve.
140	E 6	..	..	Pressure valve seat.
141	D 7	..	..	Vacuum valve.
142	E 6	..	..	Vacuum valve seat.
143	D 4	..	..	Pump chamber.
144	C 2	..	..	Pump cover plate.
145	E 6	..	..	Vacuum valve spring.
146	D 5	..	..	Pressure valve spring.
147	D 4	..	..	Crank shaft gear.
148	C 2	..	..	Pulley shaft pinion.
149	C 1	..	..	Hole in pulley shaft.
150	A 2	..	..	Upper pump bearing.
151	A 3	..	..	Port in pump.
152	A 4	..	..	Lower pump bearing.
153	D 2	..	..	Notched collar.
154	D 2	..	..	Conical guard ring.

No.	Column.			Parts.
155	E 8	..	..	Chamber in pump.
156	E 8	..	..	Port in pump.
157	A 8	..	..	Pump crank box.
158	A 5	..	..	Pump cross-head bearing.
159	A 1	..	..	Cover plate to tank.
160	D 4	..	..	Pump bearing cover.
161	D 3	..	..	Pump crank.
162	C 7	..	..	Pump cap.
163	D 4	..	..	Pump connecting rod.
164	C 5	..	..	Pump piston rod.
165	D 7	..	..	Pump valve case.
166	D 8	..	..	Pump filter case.
167	C 7	..	..	Priming check valve.
168	C 7	..	..	Throttling nipple.
169	E 3	..	..	Port in pump.
170	E 2	..	..	Pump cap.
171	E 4	..	..	Ditto.
172	B 2	..	..	Pump pulley shaft collar.

APPENDIX C.

WHEN the position of a support had been definitely determined, three pegs were fixed in the ground. The centre one being the site for the men to dig the hole, while the other two 5 feet in front and 5 feet behind the centre peg were to guide the men as to the position of the hole when the centre peg was removed. This was necessary because it was found that when the contractor's men came across rock on the centre point, they often shifted the hole to one side or the other, i. e. out of the straight, in order to avoid it. With two outside pegs put in, they could not do this without shifting these pegs as well, and that they could not do without greater risk of detection.

Two men were put on to each hole, one with a pick and the other with a shovel. Where blasting was necessary two men were put on with a jumper until the hole was bored. The method adopted for blasting was to jump a hole about 2 inches in diameter and from 3 to 4 feet deep. When about 30 holes were ready the blasting gang came round with gelatine and dynamite cartridges, electric detonators, soft wet earth, about 100 feet of heavily insulated twine, flexible cable and an electric exploder. The holes were first scraped clean, then a cartridge was let down gently by the detonator wires and a little damp earth put in and the whole rammed down carefully with a wooden ramrod. More earth was then put in and rammed down from time to time until the hole was entirely filled up. The detonator wires were then connected to the exploder, and when all hands were at a safe distance the charge was exploded. The result was generally the shattering of the rock to such an extent that very little labour was required to shift the whole of it. Sometimes two or three cartridges were inter-connected and fired simultaneously. It is useful to remember that the detonator should be fixed in the cartridges before going out on the works, using a round pointed wooden ramrod to make the hole in the gelatinous composition of the cartridge and then pressing the detonator into this hole gently but firmly. The cartridges thus prepared were placed in a stout wooden box, securely shut and provided with a strong leather strap which was passed over the shoulder of the coolie whose duty it was to carry the explosives.

The holes being dug 5 feet deep by 4 feet by 3 feet the erection of the poles was started. Prior to this the poles had been completely assembled with the exception of the insulators which were fixed after the poles were erected. First of all the posts were placed with the butts over-hanging the hole. Four ropes were attached to each support above the upper cross-arm. The poles were then lifted as high as possible by hand. At this point the butts of the poles tend to slip against the opposite side of the hole and jam. To prevent this the hole was lined with planks. This helps the men considerably in getting the poles shoulder high. When the poles had been lifted as high as possible by hand one gang was put on two of the ropes and the poles gradually pulled into a vertical position, while another gang strained on the other two ropes to keep the poles from being hauled too far over. The poles are of *sal* wood from the forests of Dehra Dun. Their average length is 30 feet and they vary in diameter at the top from 4 inches to 7 inches and at the base from 7 inches to 10 inches. Up to the point from which the lines diverge the poles are of the construction shown in plate no. XXXV. At the junction a triple pole constructed as shown in this plate is utilized. The same plate also shows the standard high tension pole. The cross-arms, too, are of *sal* wood and of the dimensions shown in the above sketches which also show the method by which they are fixed to the poles. The tops of the poles are cut in the shape of an inverted V and are protected against rot due to damp by means of a roof made of one-sixteenth of an inch thick galvanized iron sheet which secured to the pole by 6-inch iron nails as shown in the plate above referred to.

When the poles were squared up and set to the proper alignment a layer of stones was put in and rammed down tight. On top of this was placed a layer of earth, then another layer of stones, and so on until the hole was filled up. The earth was piled up to a height of about one foot above the ground level.

The poles being erected, the insulators were screwed on to the bolts and the wire payed out on the pole line. The method of doing this was as follows :—Each drum containing about 2 miles of wire was taken to a point from which the wire could be payed out down hill. Two men stood at the drum and revolved it while about ten men climbed up the first ten poles. The wire was then fastened to a rope which was passed from man to man of the gang on the pole tops. Another squad of men were placed between the poles to keep the wire off the ground and to help it along.

With regard to the straining up of the lines, the regulation under the Indian Electricity Act (rule 60) reads as follows:—

"The factor of safety of an aerial line including the supports thereof and any guard wires or bearer wires in connection therewith shall be at least four under all conditions, the maximum wind pressure being taken at 25 lbs. per square foot; for cylindrical bodies the effective area shall be taken as two-thirds of the sectional area exposed to the wind pressure."

The dips in the wires were calculated as follows :—

It was assumed that a stretched wire, if the dip is comparatively small, may be regarded as a parabola and can be treated as such without appreciable error. Knowing the breaking strain of the wire employed, divide it by the factor of safety specified in the above rule. This gives the stress at minimum temperature which has been taken at 20 degrees F. in this case. The dip for the required temperature can then be obtained from the following formulae :—

L=Span in feet.
D=Dip at 20 degrees F.
D^1=Dip at higher temperature.
S=Stress at 20 degrees F. in lbs.
S^1=Stress at higher temperature in lbs.
W=Total pressure on wire per unit length (1 foot).
$W=\sqrt{W^2+P^2}$ W=Weight of wire in lbs. per foot.
P=Wind pressure in lbs. per foot length.
T=Difference between 20 degrees F. and higher temperature.
K=Co-efficient of expansion=·00000956 per degree F. for copper.

Then $D=\frac{L^2 \times W}{8 \times S}$ and $D^1=\sqrt{D^2+L^2\left(T \times \frac{3K}{8}\right)}$

$$S^1=S \times \frac{D}{D^1}$$

Length of wire in span $=L+\frac{8}{3}\times\frac{D^2}{L}$

From these formulae a table was drawn up showing the different strains to be put on the wires for varying temperatures and spans, from 20 degrees F. to 140 degrees F. and from 50 feet to 200 feet rising in tens, both degrees and feet.

A copy of this table was given to the linesman with instructions to strain up all three wires at once with dynamometers, taking the temperature from a thermometer hung on a pole in the sun and taking the strain from the corresponding figures in the table. The length of the span was measured by him at the time of straining up.

APPENDIX D.

From the very first these pumps have given endless trouble with their first reduction of gearing. They were originally supplied with involute gearing, the pinion being of phosphor bronze and the spur wheel of cast steel. The former was 12 inches *approximately* in diameter, the width 6 inches and the pitch $1\frac{9}{16}$ inches. The ratio of reduction was 3 to 1. After the pumps had been running for a few days, the first thing that happened was the shearing of several of the teeth off the pinion. When this occurred it was decided to put in steel pinions. This was done and the next thing that happened was that several teeth of the spur wheel broke off at the roots. All these accidents were due to inferior material combined with an insufficient factor of safety in their design. New gearing was sent out by the makers and for about ten months the pumps ran fairly well with only a few minor break-downs. In October 1910, more trouble was experienced with the spur wheels due to the same cause, viz. "rotten teeth" and for over six months one pump was entirely laid up as there was no gearing available for it. The design of the gearing was then carefully considered by the Board's engineers who decided that the factor of safety was not sufficient and resolved to put in double-helical machine-cut gearing. This gearing could not be procured in India so it had to be ordered from England. In the meantime, to keep the plant going, an order was placed with a well-known Indian firm of engineers for a complete set of gearing. It was specified that this was to be of solid forged steel throughout and to this the firm in question agreed. The order was placed in December 1910 and the wheels were to be delivered in three weeks; the actual time taken to deliver them was three and a half months. Finally, when the gearing did arrive and was fitted to one of the sets, it was found that the firm had made a mistake in the manufacture and that there was a "backlash" on the wheel of nearly a quarter of an inch.

The makers were at once communicated with and to give them their due they promptly admitted that the fault was their's and in the course of another two and a half months supplied new pinions which proved to be $\frac{1}{16}$ of an inch too large. These were sent to the power station workshops and the excess was turned off. The pumps ran with this new gearing *for a few days only* when a report was received from the man in charge that a tooth of one of the spur wheels had broken off, had been carried round between the teeth of the pinion and spur wheel, bent *both* pinion and spur wheel shafts and broken up the bed-plate. On inspection of the spur wheel it was found that instead of being *mild steel* as specified it consisted of a *cast iron* centre with a mild steel ring *shrunk on*. The tooth that broke was at the *weld* and was not steel but *wrought iron* which had been inserted at the weld. When the tooth broke the weld gave way and the whole ring opened up and of course flew off the cast iron centre. As the pumps were running at full speed this ring carried everything before it. Luckily the men on duty in the engine room managed to keep clear of it. To make matters worse the very next day the same thing happened to the second set and the plant was entirely shut down, being as it was without a whole gear wheel or a shaft that would run. An attempt was made to straighten the shafts at the pump house but this proved futile. One of the least bent countershafts was actually straightened true enough to run, but to the others nothing could be done at all. It was finally resolved to make a new pinion shaft out of the countershaft that was too badly bent to be straightened. (This shaft is bigger in diameter than the pinion shaft). The damaged countershaft was accordingly sent to the power house workshops, put in the lathe and reduced to the necessary size, new keyways cut, and when finished sent back to the pump house. This shaft was so badly twisted and bent that in spite of the 1 inch extra metal on it, it just cleaned up and no more to the proper size. The keyways for the pulley and pinion had to be cut by hand; the keyway for the pulley being 24 inches long and that for the pinion 8 inches. The whole work of making the new shaft was done in 48 hours. While the shaft was being made at the power house mistries were put on to repair a number of pinions. This was done by cutting away the bad metal and "dovetailing" a new tooth in. This job proved very tedious as it had to be done by hammer and chisel but it also proved very satisfactory. Three days after the break-down occurred the pumps were started again, during 48 hours of which time the station was practically without water. Since the pumps were re-started they have not been shut down again for any lengthy period; but as the teeth of the pinions still kept breaking something had to be done. It was therefore decided by the Engineers to have wheels made of laminations of steel boiler plate. A specification was drawn up and tenders called for. The specification for these wheels was as follows :—Spur wheels to be made of eight $\frac{3}{4}$-inch steel boiler plates and two 1-inch steel plates placed on the outside of the $\frac{3}{4}$-inch plates. These plates to be pressed together, drilled and secured with $\frac{3}{4}$-inch diameter steel rivets (to be rivetted hot) turned over the top and bored out to receive a wrought iron bush of 14 inches in diameter. This bush to be bored out to $4\frac{1}{2}$-inch and key-seated. The bush to be made a tight fit for the spur wheel plates, to be of the dimensions shown in a detailed sketch and secured by suitable keys placed at an angle of 90 degrees. Pinions to be constructed in the same way but without the wrought iron bush; dimensions to be as per detailed sketch.

It was found that only one firm in India could take up work of this size, and the order was accordingly placed with them. The time stated for delivery was 30 days, but from former experience it was anticipated that this time would be at least doubled. In view of this it was decided to make a pinion, which was the part of the gearing most urgently required, at the workshops. This was rather a big job to tackle with the inadequate tools available but it was managed somehow and proved a complete success. The method adopted in making this pinion was as follows :— The only material available for making this was power pipes that were damaged in the big flood of 1909. These were 12 inches in diameter and $\frac{1}{2}$ an inch thick. The pipes were cut into plates 13 inches in diameter, heated and straightened in the blacksmith's shop. Each piece was then put in the lathe, machined over the face and top and a hole bored in the centre $\frac{1}{8}$ of an inch less than the diameter of the shaft. A template was taken off a broken pinion and the teeth scribed on the discs. The teeth were next cut out by saw and afterwards filed to within about $\frac{1}{64}$ of an inch of the correct size. Then the plates were drilled to a template and the whole of them were bolted temporarily together. After this, twelve $\frac{5}{8}$-inch holes were bored right through the whole of the plates, rhymered out, and carefully fitted bolts driven home; the nuts were next tightened up and the ends of the bolts rivetted over. When this was done the teeth were filed out to the exact size and the pinion put back in the lathe and bored out to the necessary size for the pinion shaft.

The repairs that were carried out to the gearing kept one set of pumps going until the arrival of the double helical gearing. As soon as this arrived it was fitted and the troubles as far as the gearing was concerned were at an end. This type of gearing has given every satisfaction and after running a whole year shows little or no signs of wear. The pitch of the new gearing is 1 inch and the breadth of it is 8 inches against 6 inches of the old type.

The repair to the bed-plate that was damaged was rather a lengthy affair and took over two months to carry out. This bed-plate, which is the one that was damaged when the first crankshaft broke, is now one mass of patches but for all that is still quite sound and will last as long as the rest of the pumps.

APPENDIX E.

Calculations for water distribution system.

Box's Formula $G = \left\{ (3d)^5 \times H \right\}^{\frac{1}{2}}$ and $H = \frac{G^2 L}{(3d)^5}$ where G = Gallons per minute. D = Diameter in inches. H = Head in feet. L = Length in yards.

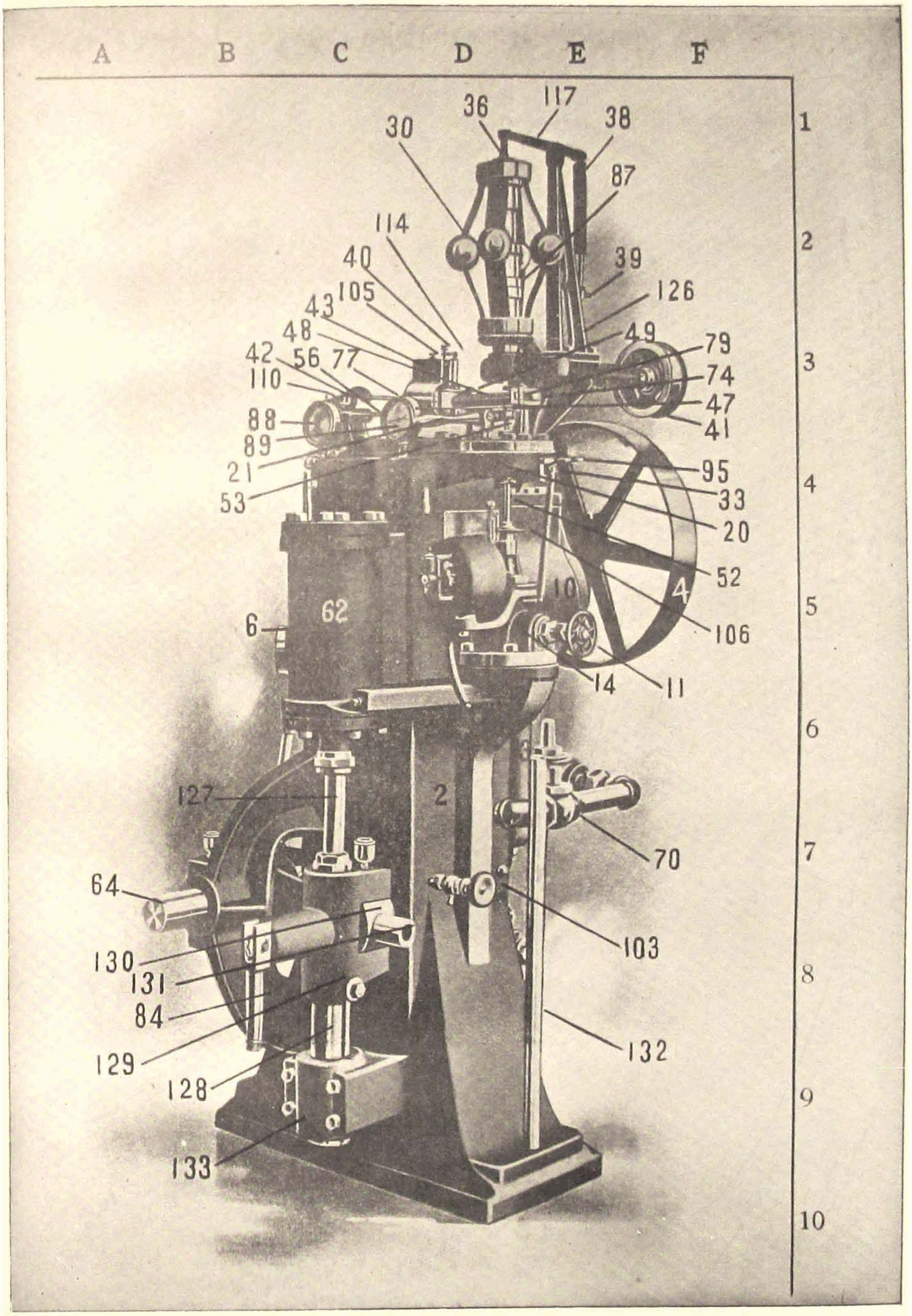
Reference to plates.	Locality of pipe.	Population to be supplied.	Allotted discharge in gallons per minute.	Diameter of pipe in inches D.	Length of pipe in feet 3 L.	Loss of head in feet H.	R. L. of Hydraulic gradient.	R. L. of ground.	Available head.
30 & 31	Vincent's Hill to Camel's Back:—								
	Chainage 0	18,000	180	4½	..	..	7,189	7,189	0
	30	18,000	180	4½	30	0·72	7,188·28	7,179	9·28
	1,160	16,500	165	4½	1,130	22·90	7,165·38	6,914	251·38
	4,160	13,500	135	4½	3,000	40·60	7,124·78	6,608	516·78
	7,725	11,000	110	4½	3,565	32·10	7,092·68	7,018	74·68
30 & 31	Camel's Back to Landour Bazar:—								
	Chainage 0	10,000	100	3½	..	..	7,010·00	7,010·00	0
	1,700	10,000	100	3½	1,700	44·20	6,965·80	6,592	373·80
	2,800	9,000	90	3½	1,100	23·27	6,942·53	6,563	379·53
	3,900	7,500	75	3½	1,100	16·20	6,926·33	6,603	323·33
	4,400	5,000	50	3½	500	3·26	6,923·07	6,641	282·07
	5,400	4,500	45	2½	1,000	28·50	6,894·57	6,697	197·57
	6,100	3,500	35	2½	700	12·05	6,882·52	6,681	201·52
	6,700	2,500	25	2½	600	5·27	6,877·25	6,687	190·25*
30 & 32	Branch line from Vincent's Hill towards the west :—								
	Chainage 3,367	18,000	180	4½	..	..	7,189·00	7,189·00	..
	3,340	18,000	180	4½	27	0·65	7,188·35	7,179·00	9·35
	3,120	1,500	15	1½	220	8·94	7,179·41	7,153·00	26·41
	2,000	1,100	11	1½	1,120	24·50	7,154·91	6,939·00	215·91
	800	800	8	1	1,200	105·32	7,049·59	6,837·00	212·59
	0	400	4	1	800	17·55	7,032·04	6,830·00	202·04
30 & 32	Branch line from Vincent's Hill towards Happy Valley and Herne Hill :—								
	(i) Vincent's Hill reservoir to B. P. T. No. 7 :—	..	..	..	..	..	7,189	7,189	0
	Chainage 0	(1,100 on 4½" main, see above).		4½	..	23·62	7,165·38	6,914	251·38
	960	3,000	30	2	960	36·80	7,128·58	6,844	284·58
	1,840	2,500	25	2	880	23·60	7,104·98	6,803	301·98
	(ii) B. P. T. No. 7 to B. P. No. 12 :—								
	Chainage 1,840	..	..	..	..	..	6,803·00	6,803·00	0
	3,370	2,000	20	2	1,530	26·21	6,776·79	6,708·00	68·79
	4,110	1,600	16	1½	740	34·20	6,742·59	6,505·00	237·59
	5,240	1,200	12	1½	1,130	29·40	6,713·19	6,420·00	293·19
	6,380	600	6	1½	1,140	18·50	6,694·69	6,384·00	310·69†
0 & 32	Branch line from 3½" main at Club Hill to Barlowganj :—								
	(i) Camel's Back reservoir to B. P. T. No. 34.	..	..	..	..	..	7,010·00	7,010·00	0
	Chainage 0	(3,900 on 3½" main, see above).		3½	..	83·67	6,926·33	6,603·00	323·33
	1,480	2,500	25	2	1,480	39·70	6,886·63	6,707·00	179·63
	(ii) B P. T. No. 34 to B. P. T. No 35 :—								
	Chainage 1,480	..	..	..	..	..	6,707·00	6,707·00	...
	2,930	2,000	20	1½	1,450	105·07	6,601·93	6,439·00	162·93
	(iii) B. P T. No. 35 to B. P. T. No. 36 :—								
	Chainage 2,930	..	..	..	..	..	6,439·00	6,439·00	..
	4,050	1,500	15	1½	1,120	45·60	6,393·40	6,220·00	173·40
	(iv) B. P. T. No. 36 to B. P. T. No. 37 :—								
	Chainage 4,050	..	..	..	..	..	6,220·00	6,220·00	..
	6,510	1,000	10	1½	2,460	110·60	6,109·40	5,935·00	174·40
	(v) B. P. T. No 37 to Tank No. 39.								
	Chainage 6,510	..	..	..	..	..	5,935·00	5,935·00	..
	8,210	600	6	1½	1,700	27·50	5,907·50	5,689·00	218·50‡

* The terminal head and discharge on this line will admit of an extension for the water supply of the Landour Cantonment by gravitation to a point at the upper end of the Landour Bazar.

† This terminal head will admit of connections being made to the houses on Herne Hill.

‡ This terminal head will admit of connections being made to St. George's College and St. Fidelis School.

Photo. No. 1.



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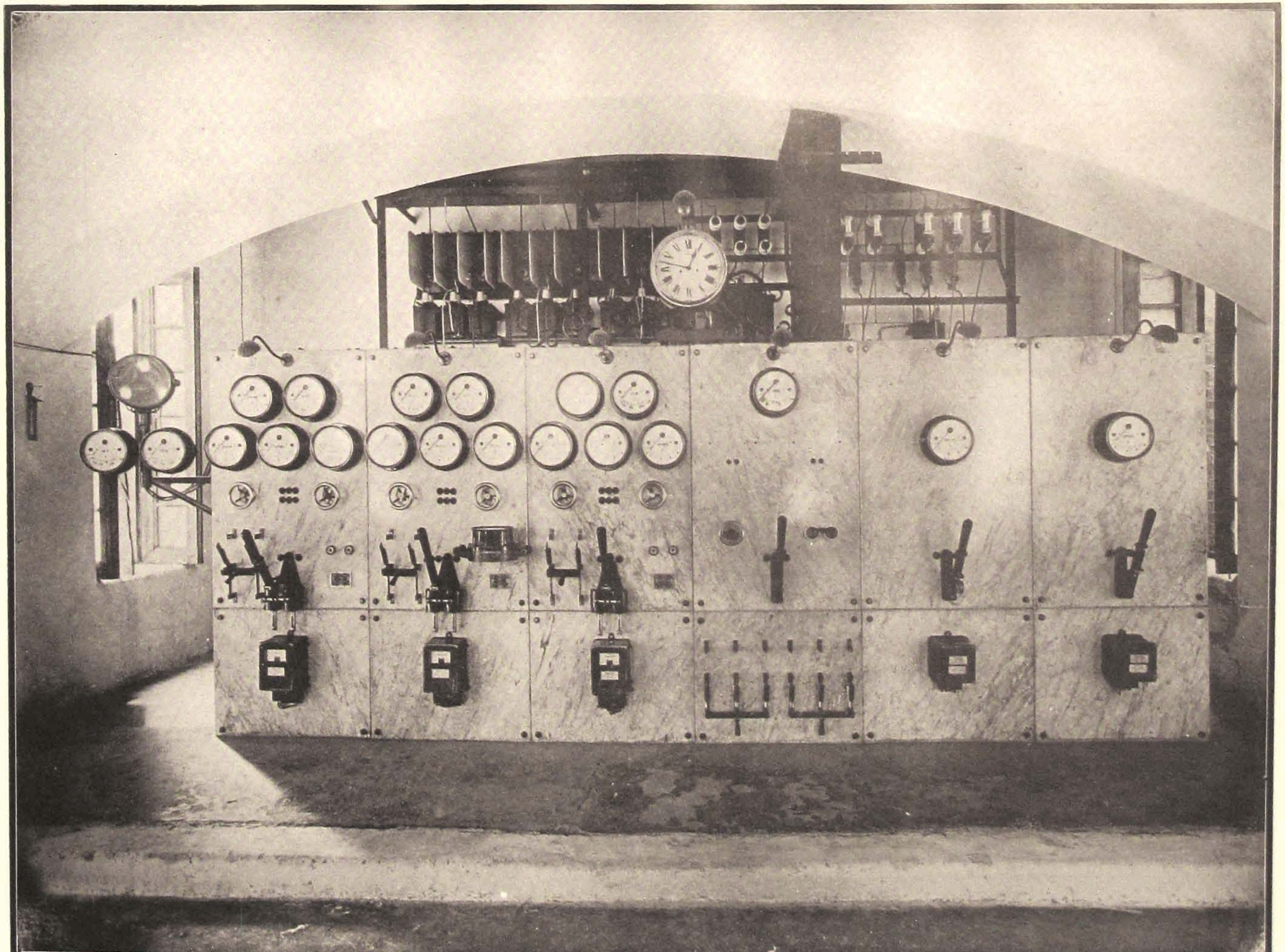
DETAILS OF GOVERNOR.

Photo. No. II.



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GENERAL VIEW OF SWITCH BOARD (POWER STATION).

Photo. No. III.

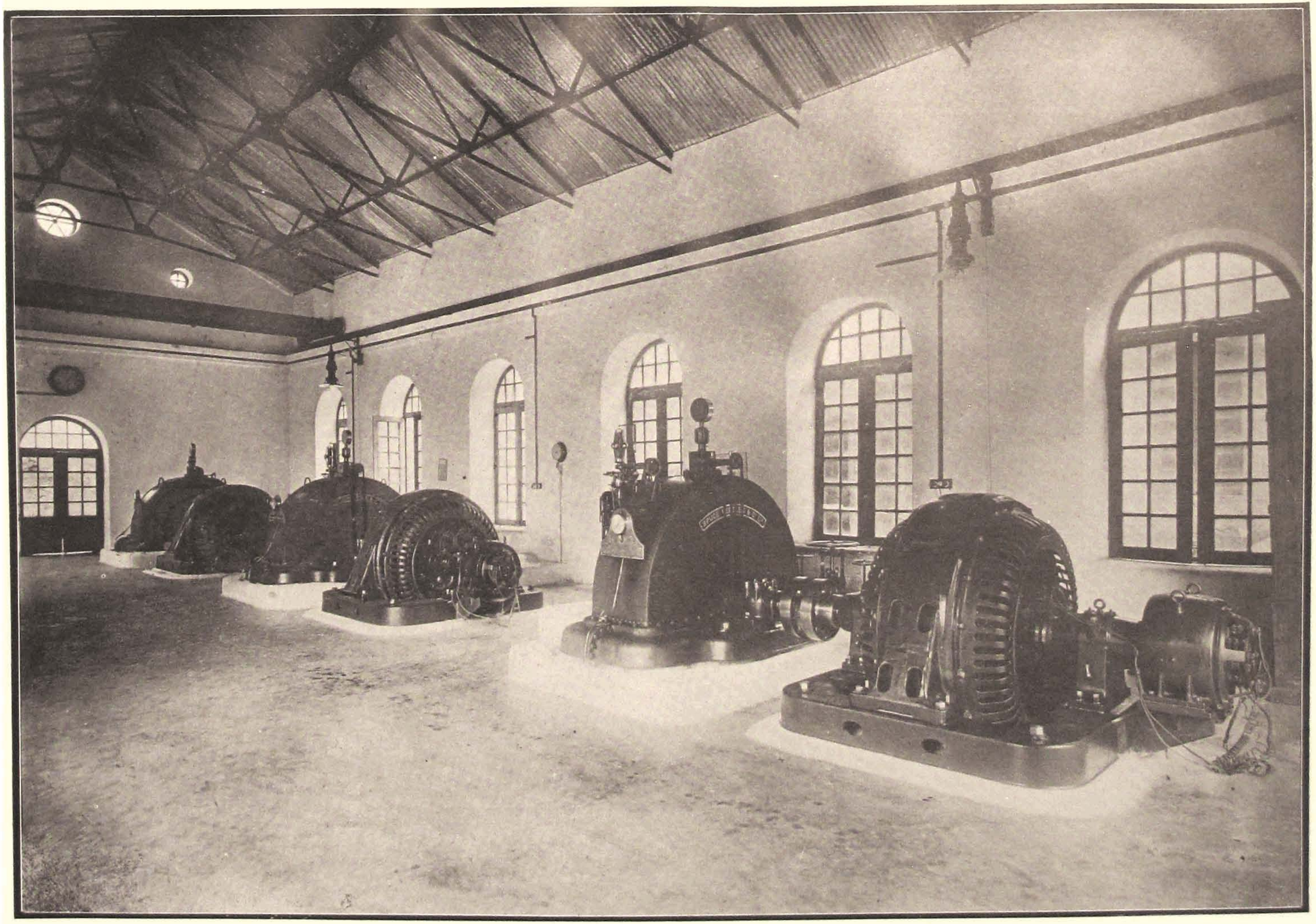


Photo.-Mechl. Dept., Thomason College, Roorkee.

INTERIOR OF POWER STATION FROM EAST.

Photo. No. IV.

Photo.-Mechl. Dept., Thomason College, Roorkee.

INTERIOR OF POWER STATION FROM WEST.

Photo. No. V.

Photo,-Mechl. Dept., Thomason College, Roorkee.

GENERAL VIEW OF POWER STATION, WORKSHOPS, BUNGALOW, ETC.

Photo. No. VI.

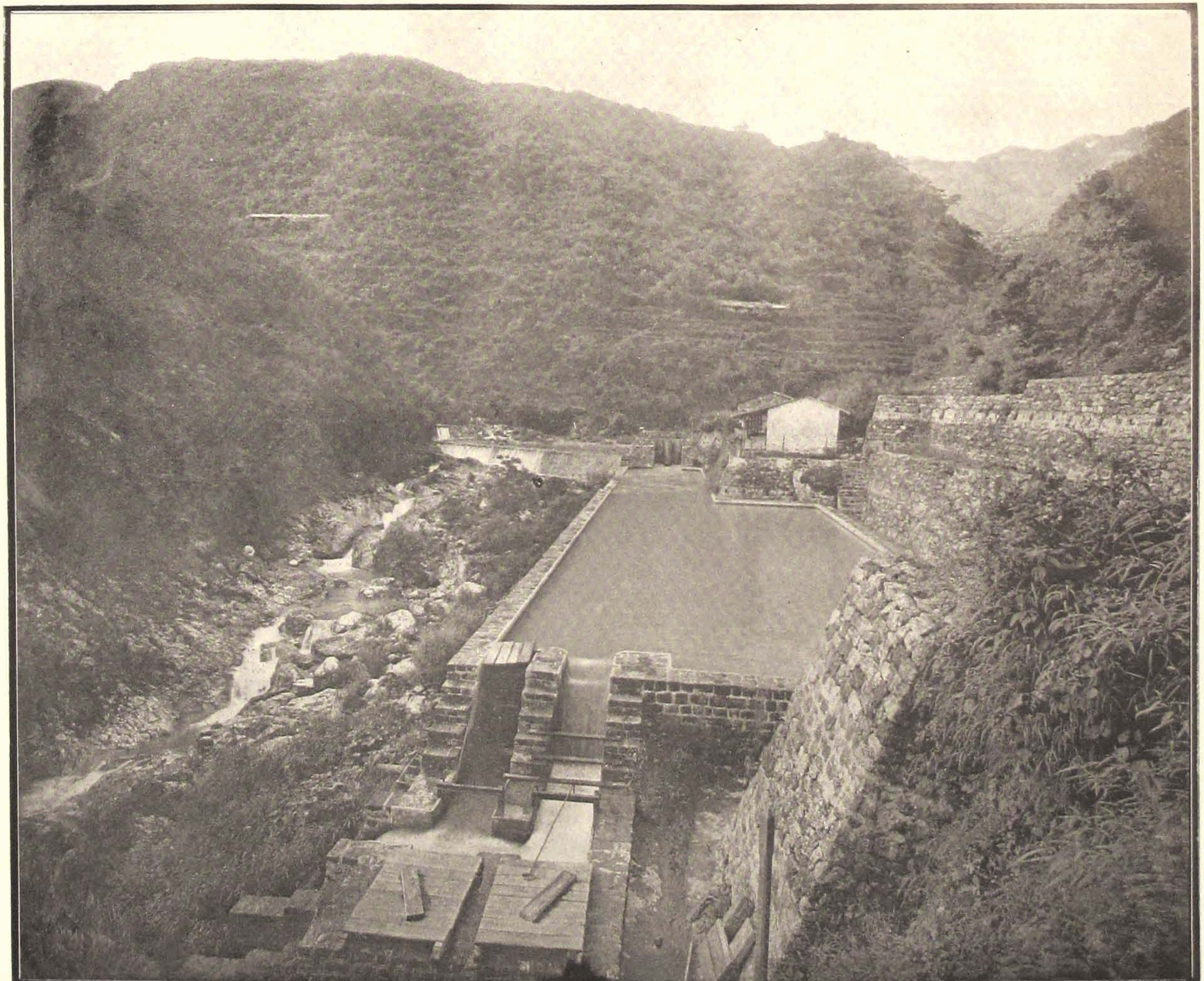


Photo.-Mechl. Dept. Thomason College Roorkee.

GENERAL VIEW OF HEAD-WORKS.

Photo. No. VII.

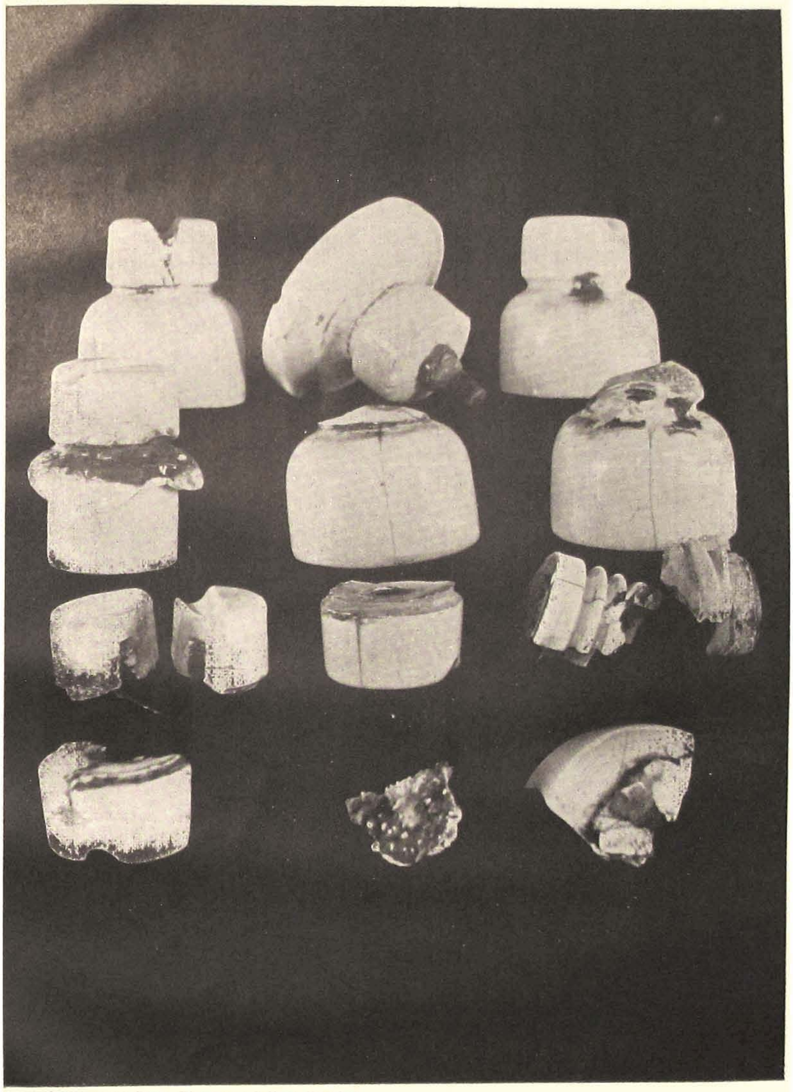


Photo.-Mechl. Dept., Thomason College, Roorkee.

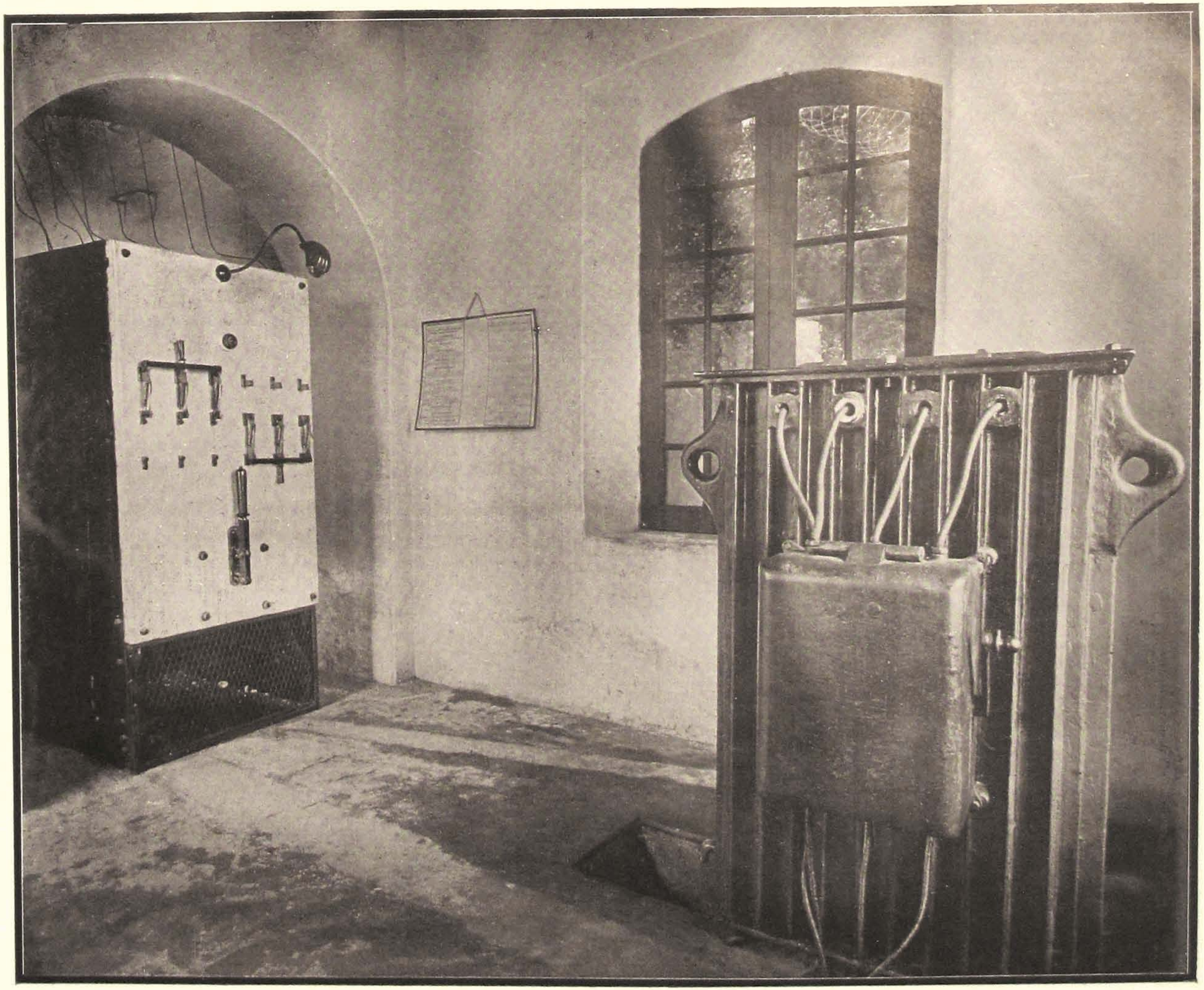
A FEW TYPICAL INSULATORS BREAKDOWNS,
(OLD TYPE H. T. INSULATORS).

Photo. No. VIII.

Photo.-Mechl. Dept., Thomason College, Roorkee.

EXTERIOR OF A SUB-STATION.

Photo. No. IX.



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INTERIOR OF A SUB-STATION,
SHOWING SWITCH-BOARD AND TRANSFORMER.

Photo. No. X.

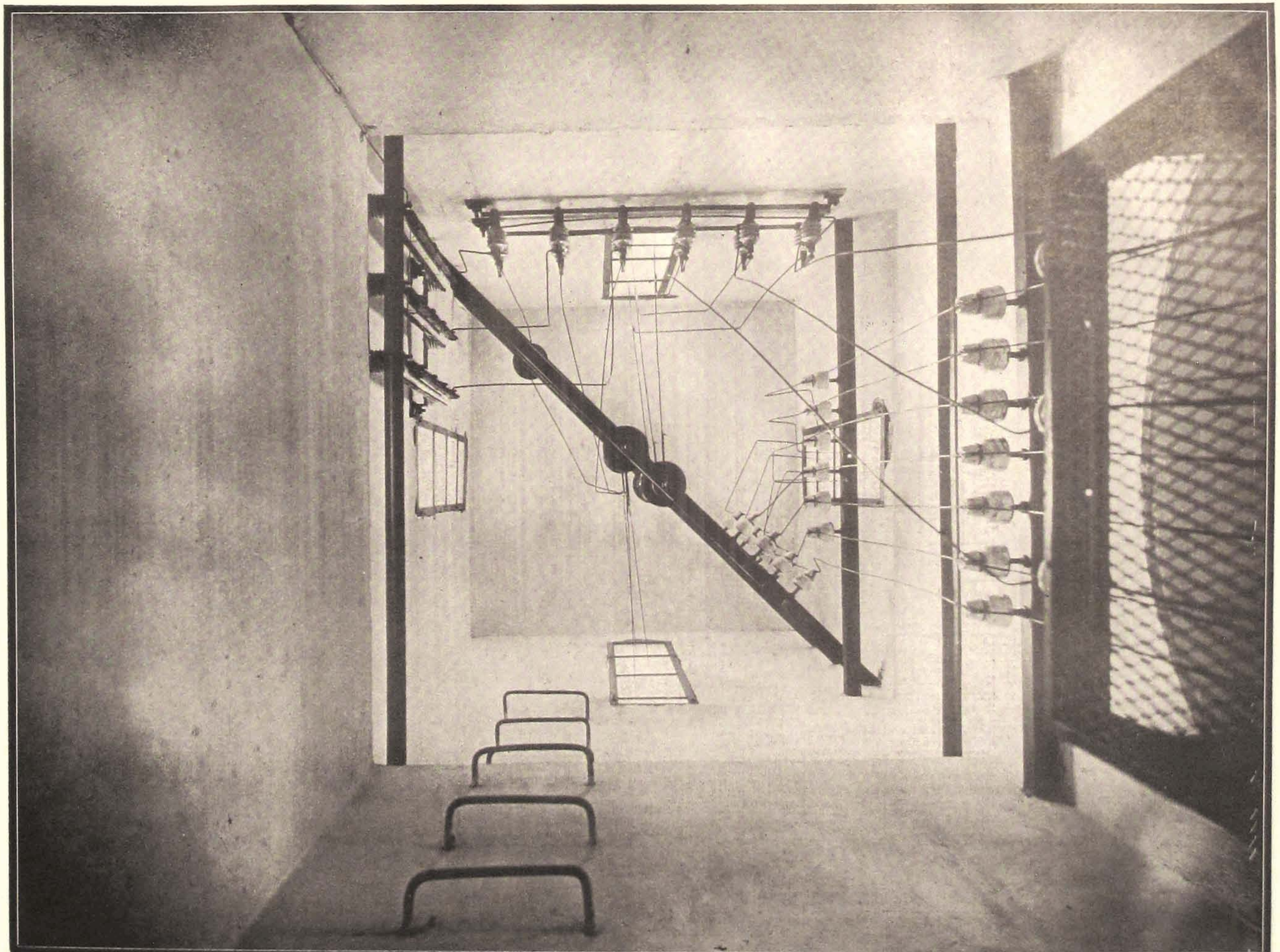


Photo.-Mechl. Dept., Thomason College, Roorkee.

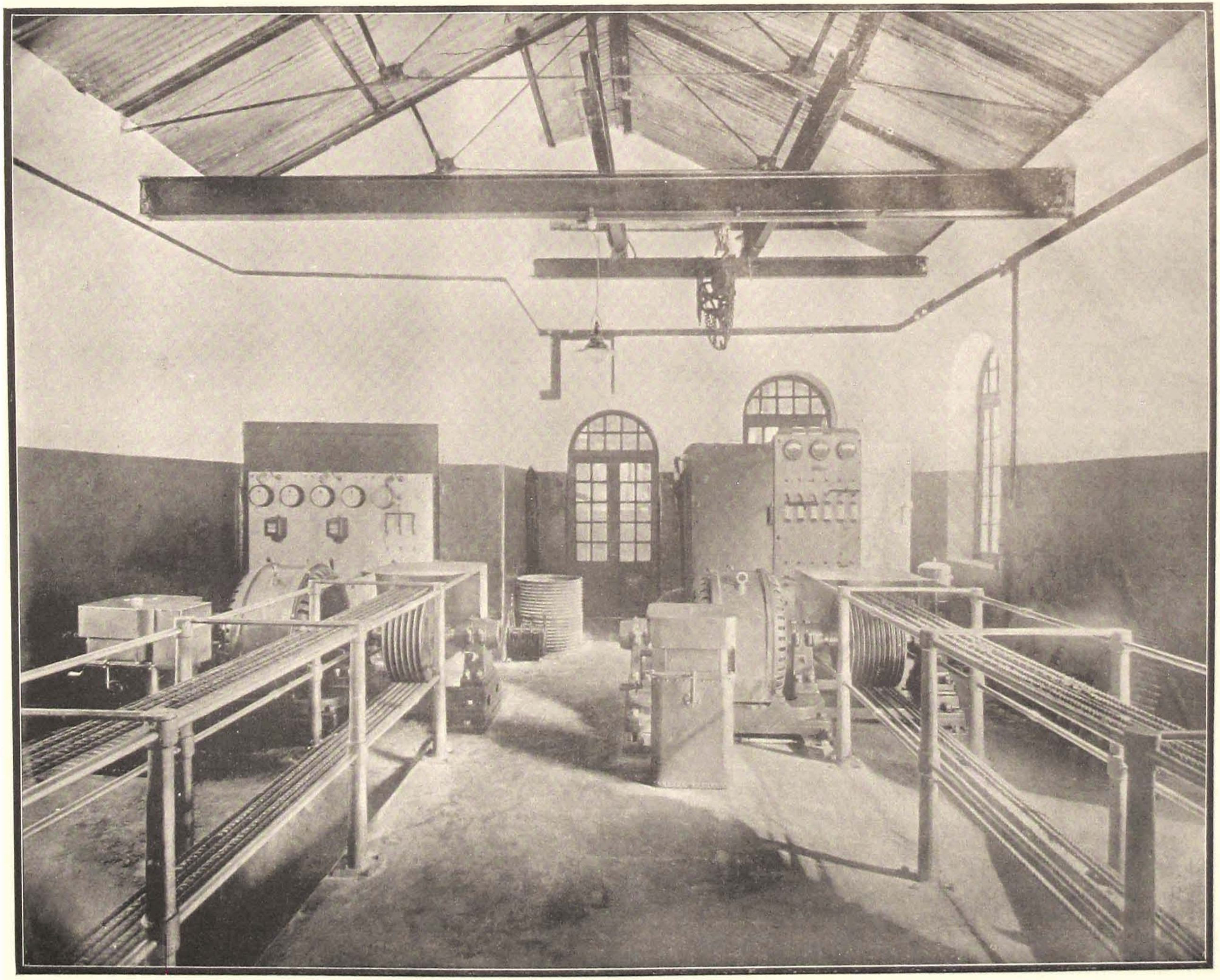
VIEW OF A SUB-STATION TOWER,
(LOOKING UPWARDS).

Photo. No. XI.

Photo.-Mechl. Dept., Thomason College, Roorkee.

GENERAL VIEW OF EXTERIOR OF PUMPING STATION AND OUT-HOUSES.

Photo. No. XII.



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INTERIOR VIEW OF PUMPING STATION,
SHOWING MOTORS, TRANSFORMER, AND SWITCH-BOARD.

Photo. No. XIII.

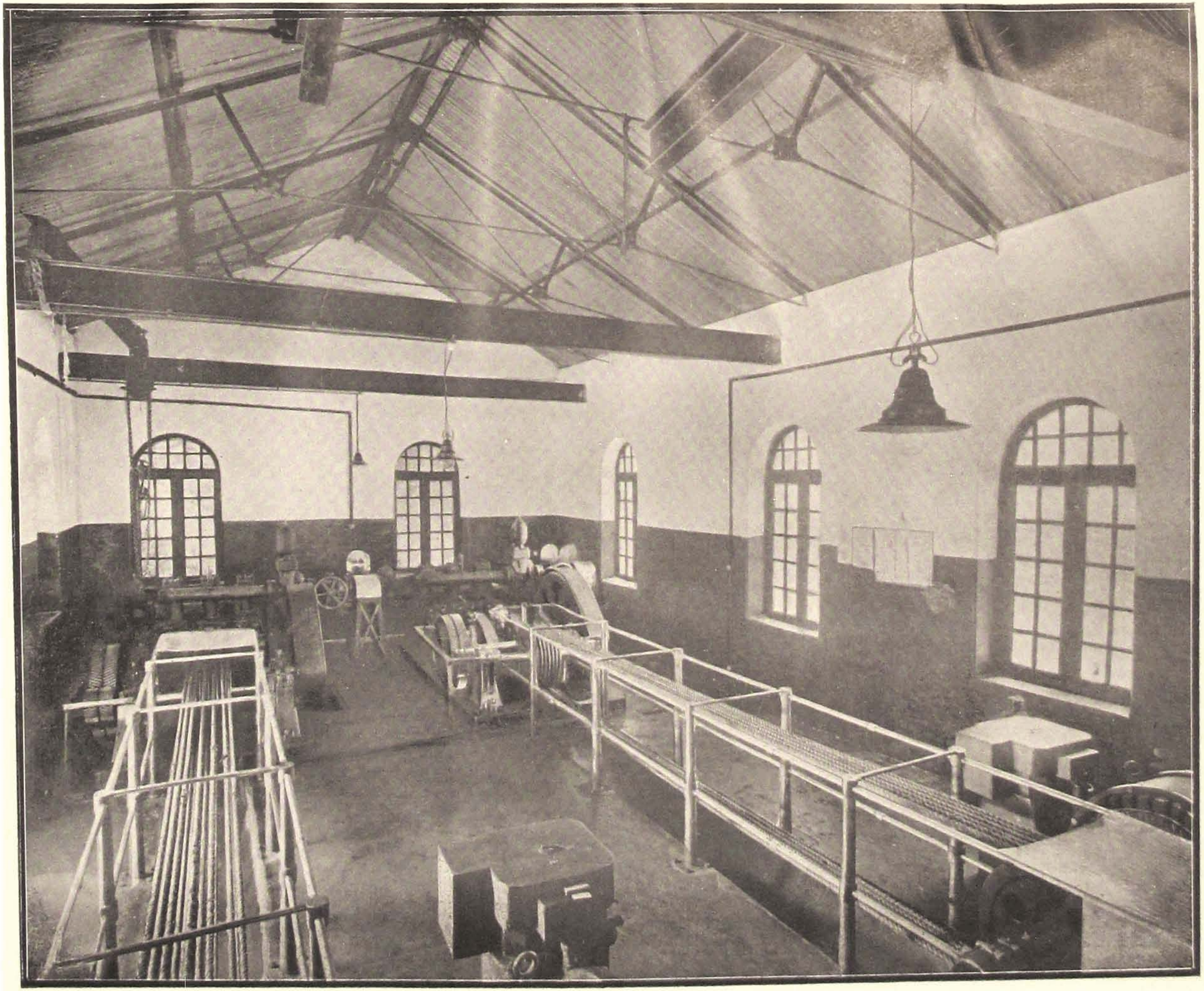


Photo.-Mechl. Dept., Thomason College, Roorkee.

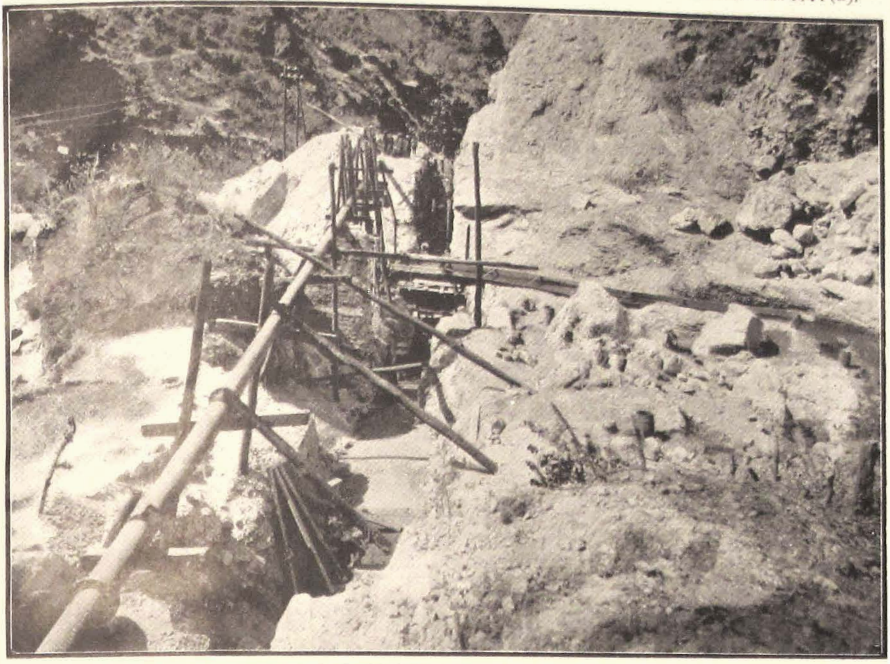
INTERIOR VIEW OF PUMPING STATION,
SHOWING PUMPS.

Photo. No. XIV.

Photo.-Mechl. Dept., Thomason College, Roorkee.

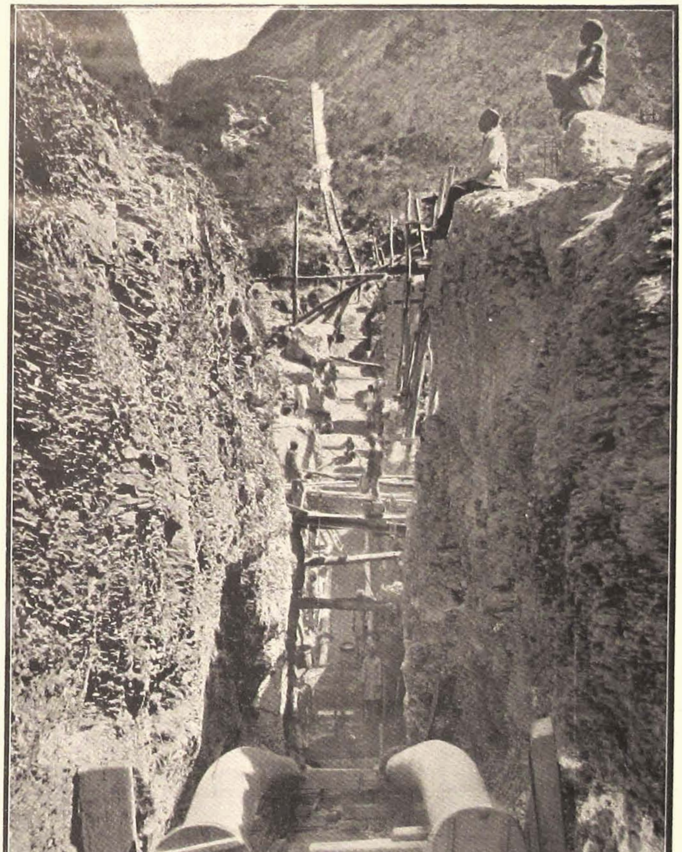
MUSSOOREE HYDRO—ELECTRIC SCHEME,
POWER PIPE LINE.

Photo. No. XV. (a).



LAYING THE POWER PIPES UNDER THE RIVER BED AT THE UPPER CROSSING, VIEW TAKEN FROM THE LEFT BANK.

Photo No. XV. (b).



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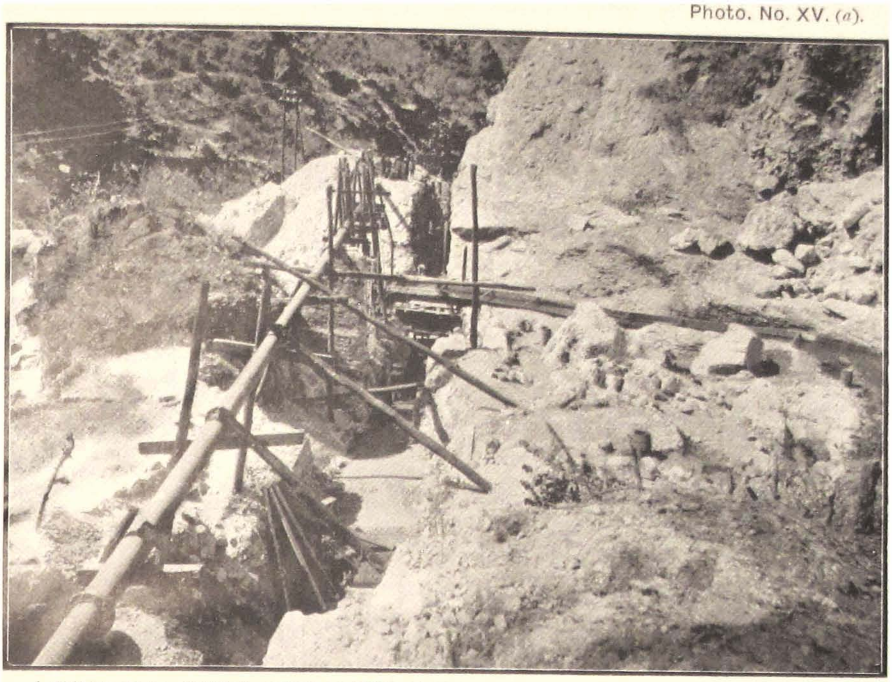
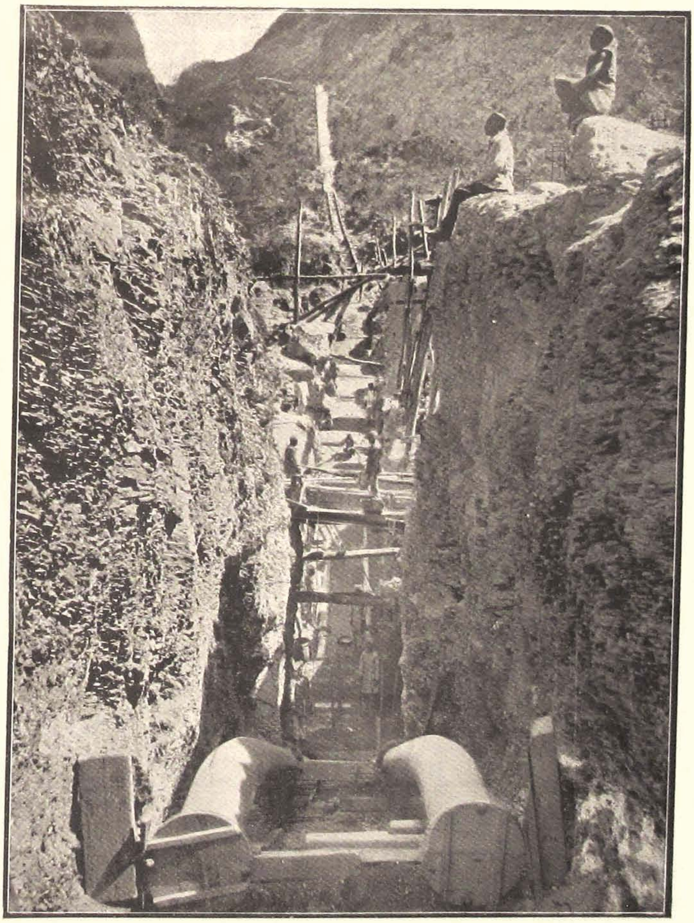
LAYING THE POWER PIPES UNDER THE RIVER BED AT THE UPPER CROSSING, VIEW TAKEN FROM THE RIGHT BANK.

Photo. No. XV. (a).



LAYING THE POWER PIPES UNDER THE RIVER BED AT THE UPPER CROSSING,
VIEW TAKEN FROM THE LEFT BANK.

Photo No. XV. (b).



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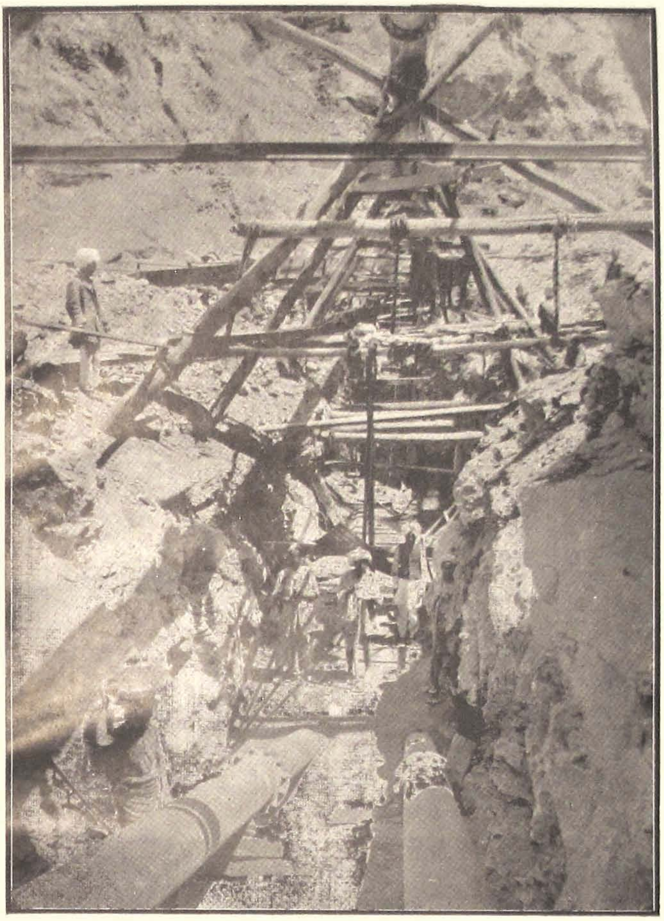
LAYING THE POWER PIPES UNDER THE RIVER BED AT THE UPPER CROSSING,
VIEW TAKEN FROM THE RIGHT BANK.

Photo. No. XVI. (*a*).



PIPE-LAYING UNDER THE RIVER BED AT THE LOWER CROSSING,
VIEW TAKEN FROM THE LEFT BANK.

Photo. No. XVI. (*b*).

Photo.-Mechl. Dept., Thomason College, Roorkee.

PIPE-LAYING UNDER THE RIVER BED AT THE LOWER CROSSING,
VIEW TAKEN FROM THE RIGHT BANK.

THE

COMPLETION REPORT

OF THE

MUSSOORIE HYDRO-ELECTRIC SCHEME

VOLUME II.—PLATES.

ALLAHABAD:
PRINTED BY W. C. ABEL, OFFG. SUPDT., GOVERNMENT PRESS, UNITED PROVINCES.

Price—Vols. I and II—Rs. 13-8-0 (20s. 3d.)

LIST OF PLATES.