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(*Paper No. 4389.*)

"Hydro-Electric Installations of the Barcelona Traction, Light and Power Company."

By Horace Field Parshall, D.Sc., M. Inst. C.E.

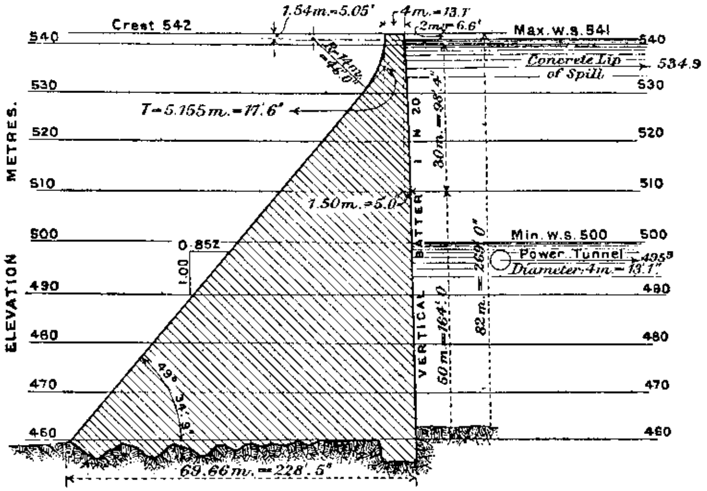
The hydro-electric installations described in this Paper are shown in Figs. 1, Plate 2, which indicate generally the character of all the works and installations, whether built or contemplated. Those on the upper reaches of the Pallaresa river begin with the small 4,500 HP. installation at Pobla, designed as an auxiliary to supply power during construction to the works at Talarn and Tremp, which derive their names from two small villages situated a few miles further down stream. The selection of a site suitable for the regulation at the Seròs power-house and some intermediate installations presented some difficulties. On the River Ribagorzana there were suitable sites for high dams, but the cañons were in general narrow, so that the storage capacity would have been limited. Further, existing water-rights permitted the diversion of a considerable portion of the river for irrigation, not an uncommon state of affairs in Spain. Many of the rivers are of diminishing volume as they flow towards the sea. On the River Segre there was a suitable site, but this would have necessitated the flooding of large and valuable areas, thereby making expropriation troublesome and costly. At Talarn there was large storage capacity at a comparatively small cost of dam and lands, and the diversion of water for irrigation did not affect an important fraction of the total flow of the river.

The Talarn dam, which is the principal reservoir and which impounds about 220 million cubic metres (7,769 million cubic feet) of water above the level of the penstocks serving the Tremp power-house, was designed primarily to store a sufficient part of the summer floods to operate the installation at Seròs on the River Segre during the winter months when the Pyrenees sources are restricted by frost. An intermediate installation on the River Pallaresa was also contemplated. Both the power-house and the dam had been begun by the late Dr. Pearson, and were about 40 per cent. completed when the Author was asked to complete that engineer's work in Spain.

The dam is situated in a gorge of yellow sandstone of comparatively satisfactory formation, although there are numerous vertical seams and the evidence furnished by weathering does not indicate a very hard material. Underneath the layer of yellow and red sandstone there is a substantial thickness of blue sandstone reaching down to the contact zone. The cañon is narrow at the site, the dam being 80 metres wide (262 feet) at the base, 204 metres (670 feet) long at the crest, 82 metres (269 feet) high from the main floor to the crest, and approximately 100 metres (328 feet) from the bottom cut-off wall to the crest. *Fig. 2* shows the cross section of the dam. This cross section was adopted as the result of negotiations between Dr. Pearson and a Commission appointed by the Spanish Government. Dr. Pearson had designed a dam complying with the "middle third" principle. The Government Commission asked for a design of such section that the dam would still be stable with leakage under the dam generally—in other words, that the unbalanced vertical component at the up-stream face, with the dam full, would not be less than the hydrostatic pressure. The experience gained by the Author when carrying out the completion of the work proved that the requirement was a reasonable one—perhaps, not necessary from the requirements as to stability, but advisable, since leakage would be less likely to occur between the structure of the dam and the surrounding rock, especially as it was found that the borings had not revealed many defects which were subsequently disclosed in the rock foundations.

The disposal of the different grades of concrete used in the dam to meet the views of the different engineers employed in the construction or to meet the requirements of the Government officials is indicated in Figs. 3, Plate 2. The work was not carried on continuously, so that a mass of the uniformity of that at Camarasa was hardly possible.

Fig. 2.



Scale: 1/1,500.

Cross Section of Talarn Dam.

The Tremp power-house, a cross section of which is shown in Fig. 4, Plate 2, is equipped with four 7,000-kilowatt horizontal type turbo-generators, one turbine at each end of the generator. The arrangement is such that the runners may be quickly replaced, since it was contemplated that it might be necessary to work the installation for considerable periods at high level, namely, 540 metres (1,771 feet), with 76 metres (249 feet) head, and at other periods at low level, namely 500 metres (1,640 feet), with 36 metres

(118 feet) head. Such a condition, however, has not arisen, the turbines being invariably worked at high level.

The Talarn reservoir was filled for the first time in 1916, and the power-house was worked during that year; but as adjustments had to be made, on account of the turbine-runners not being of the best design for the head obtaining of 27 metres (88 feet), against 35 metres (115 feet) planned for, it was not possible to obtain systematic records until 1917.

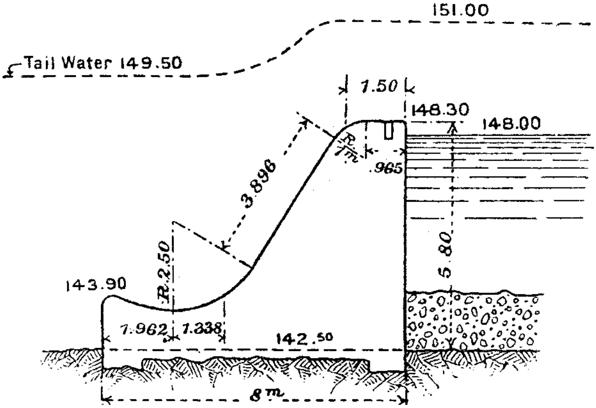
Table I in Appendix A shows the general results of the working during 1917. The data were compiled by the Author more especially as a guide to determine the character of the installation later settled upon for Camarasa. The flow of the river is given in column 1 of the Table. This was below the normal, as there was considerable drought at the end of the year but as the reservoir was full at the beginning of the year, the average head is above the normal. The average annual flow in the River Pallaresa over a period of years is about 1,390 million cubic metres (49,100 million cubic feet), and the normal output of the Tremp power-house corresponding with this is about 110 million kilowatt-hours. The general results for 1917 show an over-all efficiency of about 72 per cent., or a water-consumption of 259 cubic feet per kilowatt-hour with a head of 196 to 229 feet.

Neither the type of turbine nor the arrangement of penstocks is conducive to the highest efficiency, but the highest efficiency was not in view in the design of this station, which was looked upon as the outlet of the reservoir; the proposed installation at Barcedana, and the storage for Seròs were the primary objects in view in providing the Talarn reservoir. The installation contemplated at Barcedana was to be served by the Pallaresa canal and a pressure-tunnel. The Author's investigations did not indicate that this site was the best suited for a power-installation, one reason being that the general rock formation appeared to be of doubtful stability; and the site did not afford sufficient storage to secure the amount of regulation required to serve best the load characteristics of Barcelona.

Table V in Appendix A shows the cost of the Talarn and Tremp installation.

The installation at Aytona or Seròs, on the River Segre, of which the Rivers Pallaresa and Ribagorzana are tributaries, was the first constructed, and was finished under the direction of Dr. Pearson. This power-house is served by a canal 12 miles in length, there being a diversion-dam at Lerida, a cross section of which is given in *Fig. 5.* This diversion-dam is below the Pallaresa and Ribagorzana tributaries. These rivers are of much the same order, and the principal flow is derived in the summer months from melting ice in the Pyrenees. All of them have catch-basins in the lower levels, so that the combined flow at the Lerida weir may run to several thousand cubic feet per second in the autumn. Further, there is a diversity varying with the conditions at the different sources, so that the flow at Seròs is more regular than would be expected from the characteristics of any of these rivers singly considered. The power-house is designed for 56,000 HP., and works at 160 feet head. In connection with this canal, general cross sections of which are shown in Figs. 6, Plate 2, there is a system of earth-dams and reservoirs. These reservoirs do not store an important volume of water, about 706 million cubic feet, but are very useful for regulation over short periods, about half of the total storage being available generally for this purpose. A cross section of the power-house is shown in Fig. 7, Plate 2. Table II in Appendix A gives the cost of the Seròs installation. The annual performance of these installations is shown in Table III. There is also included the annual output of the small installation at Corbera. This is leased property, with which the Paper is not concerned.

Fig. 5.



Scale : 1/200. Dimensions in metres.

CROSS SECTION OF LERIDA DAM.

Referring in detail to the Camarasa installation, preliminary studies indicated that a few hundred feet above what is known as the confluence, there was a suitable site for a power-installation. There was a deep cañon of limestone formation, massive in character and very solid, with few bedding-planes and joints, the dip being northeast below the dam and horizontal at and above the dam. Near the bottom of the cañon the limestone was especially solid and continuous, and free from open cracks or seams of any kind. Higher up the cliff there had been a certain amount of erosion, but a great deal less than at Tremp, and not more extensive than would be consistent with a hard, dense formation. There were lateral caverns at high levels near the top, but at right-angles to the wall of the cañon. The left cañon wall rises to a height of more than 328 feet at an angle of 80° or more, and the right wall, which is more broken, rises at about 60° to about 328 feet. The borings revealed a very satisfactory state of affairs, but, as at Tremp, they did not reveal everything, since, when the foundations were cleared, a hole of approximately 706,000 cubic feet in volume was uncovered that was completely missed by the borings. These borings showed there was no need for pressure-grouting. At the narrowest point the profile was such that a dam slightly convex upstream gave the best economy in the use of material. At the left cliff behind the site the slope became much greater and afforded suitable facilities for a spillway to discharge at a safe distance below the dam. The rock excavated for this spillway afforded the material required for the construction of the dam.

Studies of the load characteristics in Barcelona in connection with the characteristics of the Tremp and Seròs installations, showed that a plant between these two, designed to utilize the normal daily river flow in a few hours, would have a greater earning capacity and utilize a greater portion of the annual flow of the river than a plant on the same general lines as those at Tremp or Seròs. Thus, the plant at Tremp in 12 hours working at 25,000 kilowatts, discharges 77 million cubic feet. The Camarasa plant could utilize this in 6 or 7 hours.

The carrying out of accurate tests over a sufficient length of time to furnish the data necessary for the design of a hydro-electrical installation of the character of that at Camarasa was attended with great difficulties. The figures finally reached are based on an average annual flow at Pobla of 45,000 million to 49,000 million cubic feet, resulting in a total average head of 228 feet above the tail-race level, with an effective head of 216 feet on the turbines. The corresponding output is 110 million kilowatt-hours. The water used per kilowatt-hour is 259 cubic feet, being an all-round average efficiency of 72 per cent., or 75 per cent. excluding penstock losses. These results are confirmed by individual plant- and machine-trials. The water utilized in an average year at the Tremp power-house is 28,593 million cubic feet. Studies show that this could be increased at Camarasa by 7,060 million cubic feet by doubling the maximum capacity of the turbines at Camarasa. This condition was also favourable to meet the peak-load requirements in Barcelona. The gain through increased reservoir-storage at Camarasa might, according to the method of working, be 1,059 million cubic feet, making an available total of 36,712 million cubic feet. No allowance has been made for evaporation loss, as certain measurements indicated that the drainage area between Tremp and Camarasa contributes substantially more than would be lost by evaporation and percolation.

A turbine-capacity at Camarasa was ultimately determined on that could utilize this flow in 6 to 7 hours. The effective storage of the Camarasa reservoir is 1,000 to 1,400 million cubic feet, hence the drawing down of water at this rate does not appreciably affect the head, and the installation can readily respond to the maximum peak-loads as they occur in Barcelona, and has a further advantage of great possibility of utilization during flood-time. The wheels at Tremp cannot utilize more than 1,665 cubic feet per second, whereas the wheels at Camarasa can utilize 3,530 cubic feet per second, the net result being that the coefficient of utilization at Tremp is about 58 per cent. as against 73 per cent. at Camarasa. The efficiency of the Camarasa plant on the basis of the experience gained at Tremp and on the trials made on the machines will approximate 80 per cent., and the corresponding water-consumption per kilowatt-hour will be at the rate of 200 cubic feet with a total head of 264 feet. The total water available for power in an average year at Camarasa is 36,712 million cubic feet, from which it follows that the corresponding output is 182 million kilowatt-hours per annum.

Table IV in Appendix A gives a general comparison of the Tremp and Camarasa plants.

Referring to the Camarasa (or Confluence) dam, the following Tables show the constants of the dam at four different levels.

The formula for the ratio of base to height for a dam of right-angled cross section, and complying with the condition of hydrostatic pressure balanced by weight component, takes the simple form :

$H = B \sqrt{G - 1}$, or $\frac{B}{H} = \frac{1}{\sqrt{G - 1}} = \tan \alpha$ (α is the angle of back to base of dam). With $G = 2 \cdot 45$, the point E where the resultant cuts the base is $\frac{2}{3} B - \frac{0 \cdot 483 B}{G}$.

G = Specific gravity of material in dam.

CONSTANTS OF THE CAMARASA (CONFLUENCE) DAM FROM 290 ABOVE DATUM.

Elevation above Datum.	H.	B.	W.	WB 2/3.	Hy.	E.	$2 - \frac{3E}{B}$.
Metres.	Feet.	Feet.	Million Lbs.	Million Foot-Lbs.	Million Foot-Lbs.	Feet.	
290	283·0	236·0	5·00	784	234	111·0	0·59
310	216·5	181·5	2·95	355	104	85·5	0·59
330	151·0	126·0	1·425	119	35·8	59·5	0·59
350	85·1	71·6	0·455	21·8	6·2	34·2	0·58

H denotes the height of the dam.
B „ breadth „
W „ weight of the dam in lbs. per linear foot.
WB 2/3 is the weight moment about the base.
Hy. foot-lbs. is the hydraulic moment.
E is the distance from the down-stream face where resultant cuts the base.
$2 - \frac{3E}{B}$ is the ratio of average working to maximum pressures with no hydrostatic pressure under the dam.

CONSTANTS OF CAMARASA DAM.—*continued.*

Elevation above Datum (Datum 290).	$\frac{2W}{B}$	P_1.		P_2.	
Metres.	Tons per Sq. Ft.	Tons per Sq. Ft.	Lbs. per Sq. In.	Tons per Sq. Ft.	Lbs. per Sq. In.
290	19·0	11·2	174·2	7·8	121·3
310	14·5	8·55	133·0	5·8	91·7
330	10·1	5·9	91·8	4·2	65·3
350	5·7	3·33	51·3	2·3	35·8

$\frac{2W}{B}$ denotes maximum pressure at the back of the dam if the hydrostatic pressure is evenly distributed over the bottom of the dam.

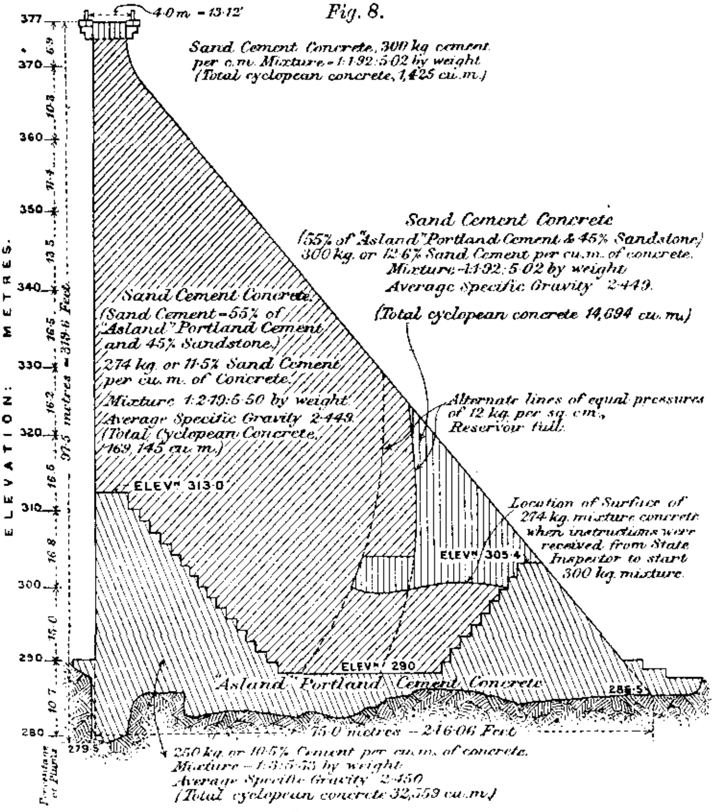
P_1, in tons per square foot, denotes pressure per square foot on the down face of the dam with dam full, if there is no hydrostatic pressure under the dam.

P_2, in tons per square foot, denotes pressure per square foot on the upward face of the dam with dam full, if there is no hydrostatic pressure under the dam.

The dam is about 105 feet long at the base and 492 feet at the crest, and it will be seen from *Fig. 8* that it is 318 feet high from the bottom of the cut-off wall to the footway and 246 feet thick at the base. It contains 280,000 cubic yards of concrete. The percentage of plums in the dam is given in Table VI (Appendix A).

These plums were of dense, hard formation and the weight of an average plum was 1·18 ton. Results indicated that, under the particular conditions at Camarasa, this percentage of plums was economical. The introduction of a greater percentage of plums was accompanied by difficulties that more than counterbalanced the saving in concrete. *Fig. 8* also shows the way the concrete was used in the dam, and Table VI shows the rate at which the construction proceeded.

Fig. 8.



Scale: 1/1,000.

Cross Section of the Camarasa (or Confluence) Dam (showing locations of the different classes of concrete, and percentages of "plums" placed at different levels).

The spillway was first designed to be an open canal, but subsequent investigation showed it could be more economically constructed as shown. It was designed by Government requirements to discharge 70,600 cubic feet per second, although no river flood has occurred during the period records were obtainable. Fig. 9, Plate 3, shows the general arrangement of the power-house, canal and penstock.

The power-tunnel is cut through the rock and is lined with cement. It is 750 square feet in cross section, 738 feet in length, and has a fall of 8·8 feet. This fall has been calculated on the basis that the power-plant might be worked at full capacity when the reservoir had been drawn down to a level of 370, corresponding with an effective storage of approximately 1,412 million cubic feet of water. The general formula used indicated that at full-load with the water standing in the reservoir at 375, this head was sufficient to give a maximum velocity of 22 feet per second, and a normal velocity at the lower level of 5·5 feet per second. And, in the extreme case at full load, the level might be drawn down to 367·5; this head would give approximately the velocity required for the operation of the turbines at full load. The penstocks, one to each main unit, are of riveted boiler-plate, are 8 feet in diameter, and are grouted in the solid rock.

In the case of the Camarasa dam, where the formation is more solidified and apparently in all ways more satisfactory than at Tremp, there is a percolation from sources unknown amounting to approximately 70·6 cubic feet per second. From the temperature-tests made it would appear that the origin of this seepage must be a considerable way back in the mountains, and is more likely due to surface-water than to the reservoir proper, in that the galleries bored in and about the reservoir when it was being completed and filled, indicated that there were no leaks from the seams adjacent to the dam.

It should be observed that in the case of the Tremp dam the cement was made on the site by the dry process. In the case of the Camarasa dam the cement was made by the Asland Cement Company. In both dams the cement clinker was ground on the spot. In the case of the Camarasa dam, very liberal use was made of the sand cement, since tests indicated that this material gave an ample factor of safety. The difficulties of transport in Spain were so great during the War that there was need for the greatest economy in cement.

Table VII in Appendix A shows the results of briquette tests made weekly.

Figs. 10, Plate 3, show the longitudinal and cross sections of the power-house, which is of reinforced concrete, and is designed to meet the local conditions and to make use of material locally available. In general, the arrangement of the switching gear, transformers, lightning-arresters, etc., does not differ greatly from that in many modern installations, hence there is no necessity for detailed description. All the plant was manufactured by the General Electric Company of America and complies in general with the latest modern practice. The generators and transformers, however, have special features, and as the tests carried out were more than usually complete and the results may be of considerable interest to engineers generally, the Author has included the results of the tests on these generators and transformers in Appendixes B and C.

The turbines were manufactured by Messrs. Escher, Wyss & Company. They have cast-iron scroll cases used for double working-pressure and cast-steel runners, and are equipped with Escher-Wyss automatic regulators, which have been found to be extremely efficient. They are of very high speed for the output, and the Author's view is that higher efficiencies are obtainable with lower-speed turbines. Such lower-speed turbines, however, are much more expensive, as are also the generators and buildings. American manufacturers who specialize in the lower-speed type of machine were asked to tender, but under the conditions obtaining during the War they declined to do so. The guarantees required are shown in Appendix D.

The generators were specially designed to meet the requirements of long-distance transmission, and a very elaborate system of tests was carried out at the works of the makers. Fairly close and inherent regulation was specified for the generators, since the Author's experience is that, for long-distance transmission work, generators of close regulation are the most satisfactory from all points of view. It will be noted that the lines from Tremp and Seròs are connected to Barcelona through Camarasa. The switching arrangements are such that the Tremp and Seròs plants can be connected to Barcelona through Camarasa, and those at Camarasa and Tremp to Barcelona through Seròs. The switchboard has all the most modern appliances for safety and automatic control, but as there are no special features other than those involved in the particular arrangements of lines, special description appears to be unnecessary.

Investigations made in 1916 and 1917 showed that the losses of energy due to phase displacement of the current by self-induction exceeded 30 million kilowatt-hours per annum, and as additional power could not be provided as soon as was required, means of meeting the demands until the new installation proposed for Camarasa could be completed, were studied. With a total output of 260 million kilowatt-hours generated per annum, 75 million kilowatt-hours were lost between the turbine-shaft and the consumer, 65 millions of which would be more or less affected by the power-factor and more or less eliminated according to the disposal of the phase-compensating arrangements. General particulars of the lines are shown in Fig. 11, Plate 3. The 110,000-volt system consists of two main circuits, one between Tremp and Camarasa, and through the Igualada

Sectionalizing Station to Sans (Barcelona)—this being the first line constructed, having duplicate conductors of 0·157 square inch in each phase. The second line is between Seròs and Sans. This is the second line constructed and has duplicate conductors of 0·196 square inch section. There is also an interconnecting line between Camarasa and Seròs, and on account of the length of this latter the length of transmission may vary slightly, but in the average case the length of transmission does not vary greatly from 120 miles. Current at 25,000 volts is taken from the Sans Station in Barcelona to Calle Mata by underground trunk mains, where it is generally distributed in Barcelona at 6,000 volts. It is also taken by overhead conductors carrying 25,000 volts to Corbera, which is the distributing centre for the 25,000-volt overhead system which supplies 50 million kilowatt-hours per annum. This 25,000-volt overhead system is now linked up with the 110,000-volt system at various points, largely reducing conductor-losses. On account of the wide fluctuations in voltage this interconnecting could not be done without condenser-regulation, which greatly reduces the fluctuations in electromotive force. The energy-loss effected by phase-displacement is $(\text{current})^2 \times (\text{resistance})$ in character. The bulk of the saving is effected in periods of heavy load. The losses in the transformers and generators vary to a less extent with the load.

It follows in designing a phase-compensation installation for the elimination of energy losses, that output during what may be termed heavy loading periods has principally to be considered. Thus these calculations were based on an assumed average working condition equivalent to 55,000 kilowatts delivered to Barcelona during 4,000 hours in the year, instead of a measured maximum of 70,000 kilowatts occurring at short intervals periodically. For voltage-regulation, maximum output is the determining factor. Thus while the total annual saving effected by phase-compensation in the Barcelona system by a properly designed system of phase-compensators would not exceed 12 per cent. of the annual output, the maximum peak-load output of this system, as determined by the limits imposed by regulation, could be increased 50 per cent. by means of a complete system of phase-compensators. The power factor in the consumers' end of the system varied between 0·67 and 0·7. Preliminary calculations showed the power-factor could be increased by phase-compensation in the ratio of 1 to 1·3 and the terminal voltages increased in the ratio of 1 to 1·2. The energy-losses directly affected by phase-displacement, as estimated before and after phase-compensation, were as given on p. 307.

Deducting 5,500,000 kilowatt-hours for condenser and other losses incident to the distribution of the additional amount, there is a net saving of 18,950,000 kilowatt-hours.

	Before Phase-Compensation.	After Phase-Compensation.	Saving in Kilowatt-Hours. Per Annum.
Generators C^2R loss . . .	6,250,000	2,200,000	4,050,000
110,000-volt conductors C^2R loss	22,675,000	9,400,000	13,275,000
110,000-volt transformer losses	17,325,000	13,600,000	3,725,000
25,000-volt system transformer and conductor losses . .	—	—	3,400,000
		Total . .	24,450,000

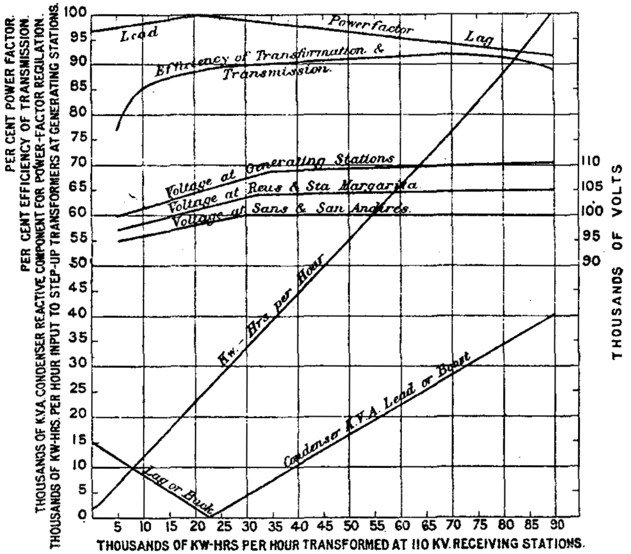
Calculations showed that a 20,000- to 25,000-kva. installation of synchronous converters installed at suitable points might be relied upon to effect such a saving. An examination of the system showed that compensation could be effected over a wide range by the use of three 5,000-kva., one 2,000-kva. and three 1,000-kva. condensers having the characteristics now given.

To be of 96 per cent. efficiency, to work on 0·04 to 0·05 leading power-factor, to have magnetic characteristics so that, at no-load excitation, 90 to 95 per cent. of the magnetization force would be in the air-gap, and the electromotive force could be increased by 50 per cent. from normal without excitation by doubling. Such machines are self-regulating over a wide range, but automatic regulators were provided for. They were installed in the 6,000-volt system as follows:—

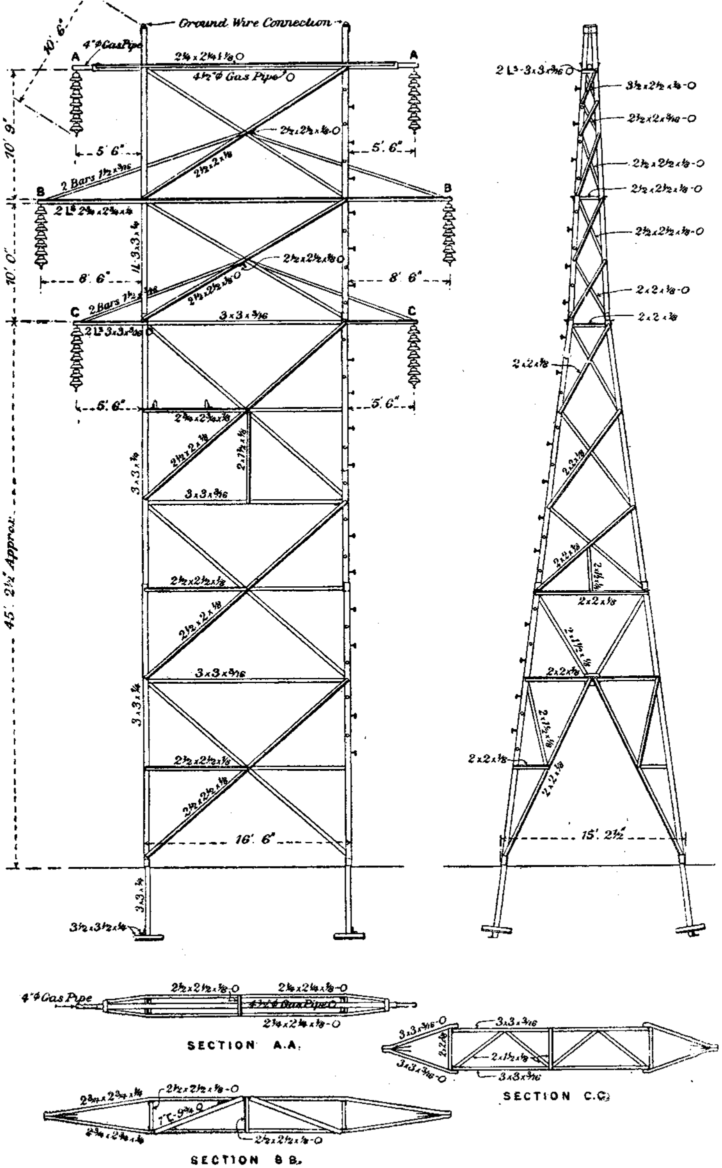
One 5,000-kva. machine at the Sans receiving station, two 5,000-kva. machines at the Calle Mata substation, which is the general distributing substation for Barcelona, and, as already stated, is connected with the Sans station through an underground system of trunk mains. Thus, the bulk of the phase-compensation acts fairly directly on the 110,000-volt transmission system. Machines of 3,000-kva. capacity were installed at the extremity of the 25,000-volt overhead system at Tarrasa, and two 1,000-kva. machines at Villaneuva, which may be regarded as another extremity of the system, in that it is half-way between Reus and Sans. The general arrangement is, therefore, that both the 110,000-volt and 25,000-volt systems are compensated, practically at the extreme points, and at points most favourable to phase-compensation. It should be stated that over-excited synchronous motors were use at certain points in connection with railway supply. They possibly contributed 10 or 15 per cent. to the general result, but were in service before the present installation was put to work, so they do not affect the accuracy of the conclusions as to the effect of the new machines.

The increased revenue derived from the saving in energy augments the possible net income by £80,000 per annum. The cost of the synchronous-condenser installation as put down during the war was considerable, the price f.o.b. New York being $154,500. In addition to this, the capacity of a transmission plant, costing well over £500,000, can be increased by 40 per cent. by increasing the capacity of the condenser-system with the growth of load, up to the carrying capacity of the conductors. Precise allocations of the savings effected have not yet been made, but in the year in which the total consumption was 186 million kilowatt-hours, the results indicated that the annual saving was not less than 10 per cent. In practice the installation works very satisfactorily, and voltage fluctuations are vastly less now than formerly, since the effect of local short-circuits is not noticeable. These phase-compensators, or synchronous condensers as they are commonly termed, are used at light loads under-excited so as to act as induction load, which avoids undue increase in voltage and permits the interconnection with the 25,000-volt overhead system at additional points, as already mentioned. *Fig. 12* shows the general characteristics of the system as worked in practice.

Fig. 12.



Figs. 13.



SECTION A.A.

SECTION C.C.

SECTION B B.

TRANSMISSION-LINE TOWERS.

Fig 11, Plate 3, shows the routes followed by the 110,000-volt lines of the Barcelona Company, also the 80,000-volt lines of the *Energia Electrica de Cataluna.* This last-named company, by agreement with the Barcelona Company, has the right to participate in the general supply to the extent of 40 per cent. of the total.

The lines from Seros to Camarasa and Camarasa to Barcelona were designed by Dr. Pearson, and are of a type which was commonly accepted as the best some years ago. The conductors are stranded and are of 200,000 circular mils cross section. The insulators are of the pin type with four petticoats. After a few years this type of insulator gave a great deal of trouble, and was unable to withstand the stress of storms. The line from Seròs to Barcelona, which was constructed under the Author's direction, is equipped with suspension insulators, seven in series, and has stranded conductors of 250,000 circular mils section. Standards are designed for straight runs with average spans of 650 feet. They are equipped with two lightning-guard wires, $\frac{3}{8}$ inch in diameter. They are designed for wind-pressure due to a velocity of 100 miles per hour, with $\frac{1}{2}$ inch of sleet on the wires ; the towers to remain stable with two wires broken. Experience has shown that such conditions can be met with towers of this design. *Figs. 13* show the design of tower used. The line from Camarasa to the Igualada sectionalizing station, where the Barcelona supply is linked up by 25,000-volt conductors, has been reconstructed in order to use the suspension type of insulator, and is equipped with six in series of the Hewlett type.

The cost of the Camarasa installation to date (two 12,500-kilowatt units installed) is approximately £1,370,000, and the details are shown in Table VIII (Appendix A). With five units installed the cost will be increased by £375,000, and the capital cost per kilowatt will be £27·9. The work was carried out under favourable conditions so far as labour costs were concerned, and it may be added that such an installation could not be provided on this basis at the present time.

The Paper is accompanied by thirteen drawings, from which Plates 2 and 3 and the Figures in the text have been prepared, and by four Appendixes.

[APPENDIXES.

APPENDIXES.

APPENDIX A.

TABLE I.—GENERAL RESULTS OF TALARN FOR 1917.

Month.	1	2	3	4	5	6	7
1917.	Flow. Million Cub. Ft.	Reservoir Level. Metres.	Million Cub. Ft.	Kilowatt-Hours. Millions.	Mean Head. Feet.	Cub. Ft. per Kilowatt-Hour.	Million Cub. Ft.
January . . .	2,223	540·0	7,766	6·852	244·0	252	1,729
February . .	1,694	536·0	6,565	9·778	226·3	257	2,541
March . . .	2,824	531·2	5,118	12·080	213·2	273	3,282
April . . .	3,177	525·1	3,883	5·765	215·1	271	1,341
May	12,072	533·7	5,930	6·131	240·0	242	1,490
June . . .	9,178	537·4	6,883	5·013	240·7	241	1,200
July. . . .	3,988	539·2	7,236	7·528	247·3	234	1,800
August . . .	2,294	540·0	7,766	10·068	246·0	237	2,386
September . .	1,553	537·0	6,707	9·772	233·5	248	2,435
October . .	1,270	535·0	5,824	10·337	221·0	262	2,672
November . .	1,870	529·0	4,765	8·762	207·9	270	2,456
December . .	953	524·0	4,236	5·859	194·8	300	1,750
	43,096	..	..	97·915	..	..	25,082

Column 1 shows the water flowing into the Talarn reservoir measured by a weir placed in the Pallaresa at Pobla.

Column 2 shows the reservoir-levels.

Column 3 shows the number of million cubic feet of water of effective storage in the reservoir.

Column 4 shows the kilowatt-hours generated in each month.

Column 5 shows the estimated mean head during the month.

Column 6 shows the average water-rate per kilowatt-hour during the month.

Column 7 shows the cubic feet of water used in generation during the month.

TABLE II.—COST OF SERÒS INSTALLATION.

	£
Roads, bridges, mills, etc., in connection with franchise	59,670
Intake dam	50,280
Dams and regulation system	171,350
Power-canal system	576,460
Power-plant buildings	154,120
Hydraulic equipment	80,080
Electrical ,,	154,990
Miscellaneous ,,	19,710
Tailrace ,,	85,900
Testing and starting	5,000
Permanent quarters	11,900
Administration and general charges	482,800
	1,852,260

TABLE III.—PARTICULARS OF STEAM AND HYDRAULIC GENERATION AT THE SEVERAL STATIONS.

	Kilowatt-Hours Generated.			
	1917	1918	1919	1920
Steam generation	5,340,725	5,024,361	80,190	386,530
Hydraulic generation—				
Pobla	6,632,010	11,128,650	9,980,216	2,735,230
Corbera	6,404,870	6,089,110	6,853,790	4,055,030
Seròs	131,873,500	136,469,600	90,557,500	123,342,814
Tremp	97,947,600	90,112,800	111,278,800	91,221,167
Camarasa	..	..	..	21,444,100
Total	248,198,705	248,824,521	218,750,496	243,184,871

Pobla is a small plant installed principally for use during construction.

Corbera is a small plant leased to the Company.

The remaining three stations are those dealt with particularly in the Paper.

TABLE IV.—SHOWING COMPARATIVE RESULTS IN AN AVERAGE YEAR.

	Rated Power. Kw.	Kw.-Hours. Millions per Annum.	Annual Flow. Million Cubic Feet.	Water Utilized. Million Cubic Feet.	Total Mean Head. Feet.	Average Effective Head. Feet.	Turbo-Generator Efficiency. Per Cent.	Over-all Efficiency. Per Cent.	Net Efficiency of Plant without Penstock Loss. Per Cent.	Cubic Feet per Kw.-Hour.	Hours Use per Annum.	Normal Water-Rate. Cubic Feet per Sec.
Tremp Plant .	28,000	110	47,655	28,593	228·2	216·5	77·0	72·5	77·0	266	5,240	1,482
Camarasa Plant .	62,500	182	47,655	36,712	270·6	264·0	80·5	76·7	80·5	200	3,640	2,965

TABLE V.—COSTS OF TALARN AND TREMP INSTALLATION.

		£
Alterations to roads and canals in connection with franchise . . .		24,860
Dam :—	£	
Care of water	29,140	
Excavation	78,480	
Preparing foundation	80,230	
Concrete	461,020	
Irrigation outlet	2,530	
Automatic gates	25,650	
Spill-way	62,920	
Log-way	2,410	
		742,380
Power-plant system		157,060
Buildings		60,030
Hydraulic equipment		60,000
Electrical ,, ...		106,850
Miscellaneous ,, ...		3,130
Tailrace ,, ...		9,000
Testing and starting		100
Irrigation-canal system		55,900
Permanent quarters		3,500
Administrative and general charges		414,670
Land		189,220
		1,826,700

Cost of the 110,000-volt transmission line shown on the plan was approximately 1,000,000

TABLE VI.—CAMARASA DAM.—PROGRESS OF CONCRETING.

Month.	Placed during Month.					Cyclopean Concrete Placed to Date.	Percentage Complete of 283,140 Cubic Yards.
	Concrete from Mixers.	Mortar for Bonding.	Plums.	Plums.	Total Cyclopean Concrete.		
	Cubic Yards.	Cubic Yards.	Cubic Yards.	Per Cent.	Cubic Yards.	Cubic Yards.	
1919							
February . .	6,058	7·8	637	12·3	6,702	6,702	3·1
March . . .	13,302	41·0	1,784	15·3	15,129	21,832	10·1
April . . .	16,277	58·0	3,083	20·6	19,419	41,251	19·2
May . . .	19,914	98·8	4,154	22·3	24,168	65,419	30·4
June . . .	14,318	84·0	2,845	21·4	17,248	82,668	38·4
July . . .	17,396	127·0	4,015	24·1	21,539	104,208	48·4
August . .	18,846	140·0	3,221	18·8	22,207	126,415	58·7
September .	21,903	132·0	4,210	20·8	26,247	152,669	70·9
October . .	21,732	104·0	4,401	21·8	26,237	178,900	83·2
November .	18,812	78·0	3,654	21·0	22,544	201,445	93·7
December . .	15,226	76·0	2,627	18·9	17,930	219,376	102·0
1920							
January . .	11,771	83·0	1,617	15·6	13,471	232,848	108·2
February . .	13,250	76·0	1,757	15·0	15,085	247,933	115·3
March . .	9,972	75·0	1,268	14·5	11,316	259,249	120·6
April	10,302	65·0	1,218	13·6	11,585	270,835	124·2
May . . .	5,115	78·0	594	12·3	5,738	276,573	127·0
June . . .	1,392	39·0	107	9·1	1,539	278,112	127·0

TABLE VII.—TESTS OF CEMENT.

	Compressive Strength in Lbs. per Square Inch.					Tensile Strength in Lbs. per Square Inch.					
	Age 7 Days.	Age 28 Days.	Age 3 Months.	Age 6 Months.	Age 1 Year.	Age 1 Day.	Age 7 Days.	Age 28 Days.	Age 84 Days.	Age 6 Months.	Age 1 Year.
Asland Portland Cement.											
Neat . . .	9,400	13,500	14,200	15,900	16,700	235	655	730	740	750	730
Mortar 1:3 .	6,450	7,700	9,700	10,500	11,500	..	295	358	445	480	490
Sand Cement:											
55 per cent. Portland cement, 45 per cent. sandstone.											
Neat . . .	4,720	7,150	9,700	10,500	11,000	108	370	492	590	640	662
Mortar 1:3 .	4,350	5,850	7,350	8,200	8,750	..	216	295	365	405	420
7-*centimetre Cubes of Mortar* poured weekly at the dam mixers from the 274 kg. sand-cement mixed and screened, wet, through a 9·42 mm. screen . .	1,160	1,570	2,060	2,370	2,650	..	..	..	..	..	..

TABLE VIII.—COST OF THE CAMARASA INSTALLATION.

	£
Concessions and water-rights	14,155
Lands	80,964
Foreign alterations	37,018
Dam	510,776
Gates, canal, tunnel- and pressure-pipes	71,106
Power-house building including transformer room	91,857
Equipment, power-house	141,237
Equipment, transformer-station	104,249
Testing and starting	1,951
Camps and miscellaneous equipment	44,238
Miscellaneous expenses, including camp expenses	91,536
Administration and general expenses	142,358
Government work	22,808
Plant-salvage	16,523
	1,370,776

APPENDIX B.

GENERATORS.

11,250 kw. maximum continuous, 14,060 kva. at 80 per cent. power-factor 16 pole, type ATB, 375 revolutions per minute, 6,600-volt, three-phase, 50-cycle vertical-shaft alternating-current generator, each complete with direct-coupled exciter, 68 kw. capacity at 250 volts. To comply with following :—

Output.	Kva. and Power-Factor.	Degrees Centigrade.
Kw.	Per Cent.	
9,000	9,000 at 100	30 increase
9,000	11,250 ,, 80	35
11,250	14,060 ,, 80	40

Overspeed.—The generators were tested at an overspeed of 80 per cent. above normal.

Efficiency.—The efficiencies at rated voltage and frequency, including load losses, frictions and windage, were as follows:—

	Per Cent.
11,250 kw. (11,250 kva. – 100 per cent. power-factor)	97·1
9,000 kw. (11,250 kva. – 80 ,, ,,)	96·3
4 500 kw. 5 625 kva. – 80 ,, ,,)	93·7

Insulation Test.—The windings were tested as follows :—

	Volts.
Alternating-current generator stator	14,200
,, ,, field	2,500
Direct-current exciter	1,500

Flywheel Effect.—The revolving part of the generator has a flywheel effect expressed in wr^2, i.e., weight in pounds multiplied by (radius of gyration in feet)^2 of not less than 1,200,000 lb.-ft.^{2}

Summary of Losses shown by Tests.

Load in kva.	5,625	11,250	11,250	14,060
Power-factor	0·8	0·8	1·0	0·8
Load in kw.	4,500	9,000	11,250	11,250
Volts at terminals	6,600	6,600	6,600	6,600
Amperes	492	985	985	1,230
Stator I^2R loss	7·38	29·60	29·60	46·45
Rotor I^2R loss	23·40	36·10	22·35	44·50
Exciter arm I^2R loss	0·54	0·83	0·51	1·02
Core loss	97·00	97·50	97·50	98·00
Stray load loss	10·20	22·40	22·40	28·70
Friction and windage	75·30	75·30	75·30	75·30
Total of above losses.	213·82	261·73	247·70	293·97
Output in kw.	4,500	9,000	11,250	11,250
Input	4713·8	9261·7	11497·7	11543·9
75-degree efficiency	95·4	97·2	97·7	97·5

APPENDIX C.

The transformers are of the 4,700 kva. core-type, oil-immersed, water-cooled, single-phase, 50-cycle step-up transformers of the following specified characteristics :—

Transformer rating in kva.	4,700 kilowatts
Total I^2R	30 ,,
Core loss	24 ,,
Reactance	12·0 per cent.
Impedance	12·0 ,,
Exciting current	3·61 ,,
Regulation at 100 per cent. power-factor	1·25 ,,
Increase of temperature by resistance	25° C.—45° C.
Efficiency full-load	98·75
,, half-load	98·74
,, quarter-load	98·73

INSULATION TESTS.

The transformers, when filled with oil and at approximately the operating temperature, were to withstand the following test voltages for a period of one minute, determined by sphere-gap calibration.

From high-voltage winding to low-voltage windings and core	221,000 volts
From low-voltage windings to core	14,200 ,,
Across full windings	twice the normal

APPENDIX D.

OUTPUT AND EFFICIENCY.

Net head	236	246	255 ft.
Quantity of water	746	760	773 cu. ft. per sec.
Output	16,400	17,500	18,500 HP.
Speed			375 r.p.m.
17,500 HP. 246 feet head			80 per cent.
13,150 HP.			84 ,,
8,750 HP.			78 ,,

GOVERNING.

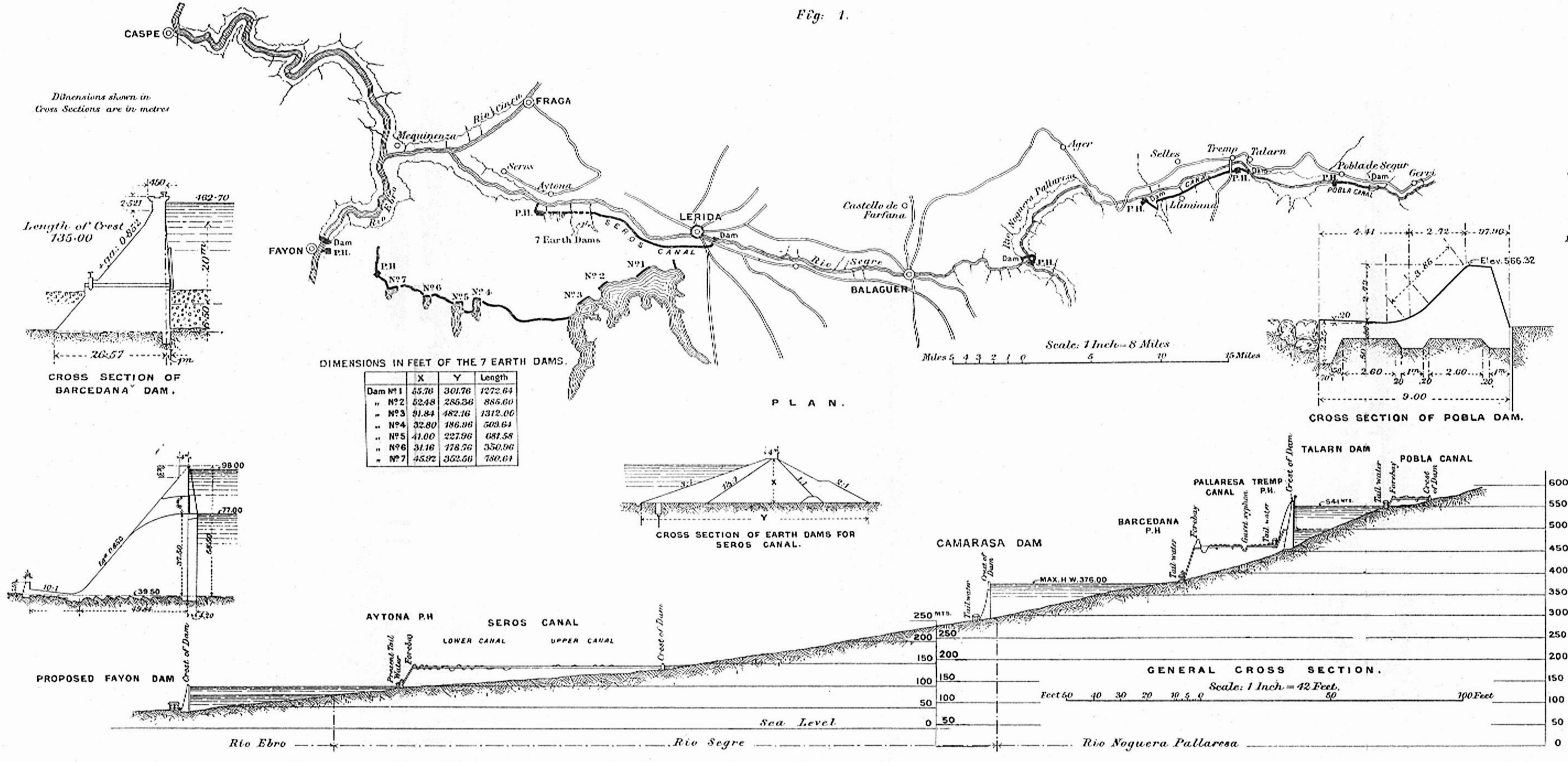
Following loads	4,375	8,750	17,500 HP.
Increase of speed (maximum)	1½	4	14 per cent.
Increase of pressure (maximum) over static pressure			18 lbs.

assuming the following conditions :

Total flywheel effect in the generator at 375 r.p.m. 1,200,000 lb.-ft.^{2} expressed in terms of weight and radius of gyration.

HYDRO-ELECTRIC INSTALLATIONS OF THE BARCELONA TRACTION LIGHT AND POWER COMPANY.

PLATE 2.
BARCELONA
HYDRO-ELECTRIC INSTALLATIONS



PLAN.

CROSS SECTION OF BARCEDANA DAM.

DIMENSIONS IN FEET OF THE 7 EARTH DAMS.

	X	Y	Length
Dam Nº 1	55.76	301.76	1272.64
" Nº 2	52.48	285.36	885.60
" Nº 3	91.84	482.16	1312.00
" Nº 4	32.80	186.96	509.64
" Nº 5	41.00	227.96	681.58
" Nº 6	31.16	178.76	350.96
" Nº 7	45.92	362.56	780.64

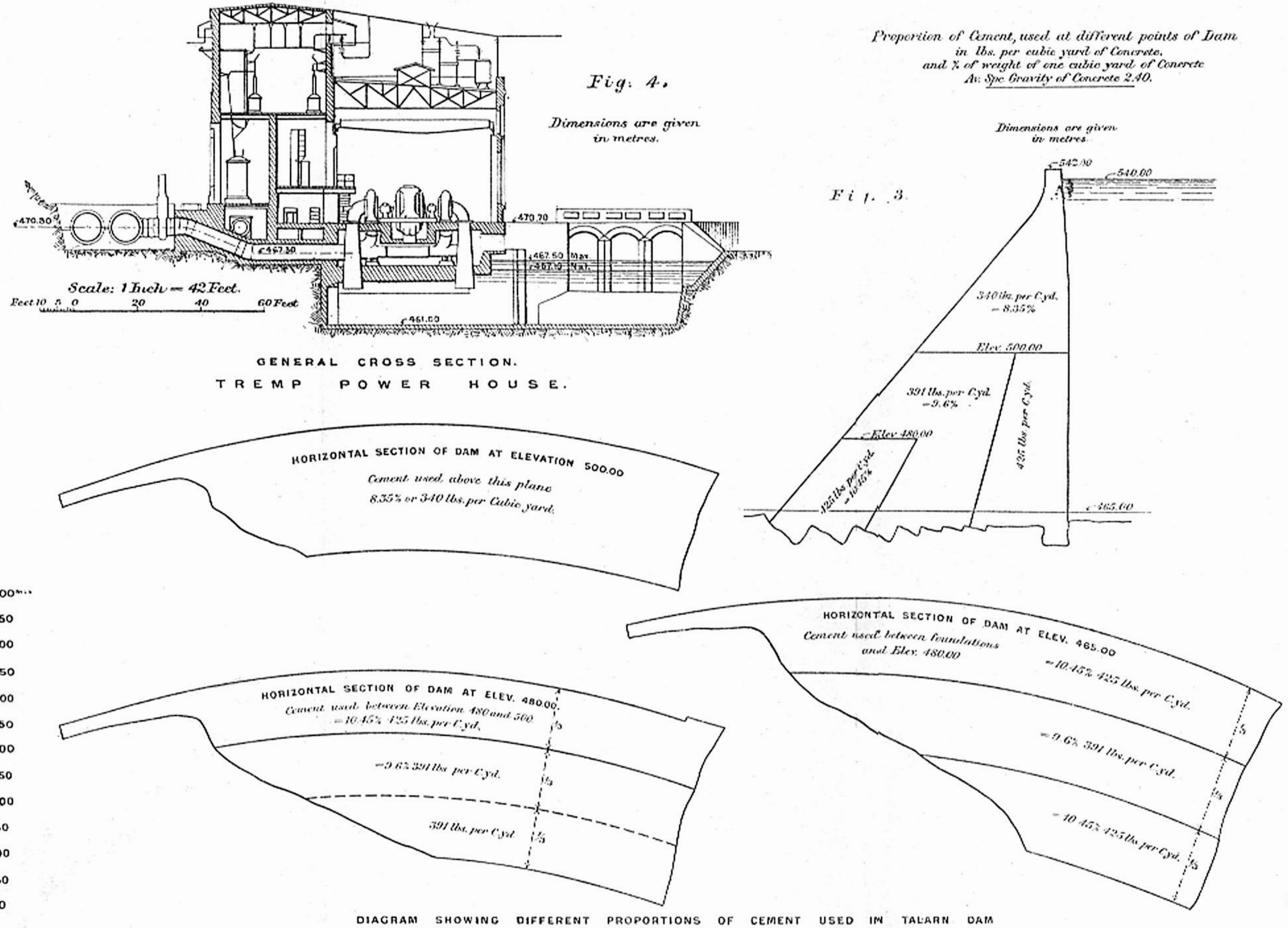
CROSS SECTION OF POBLA DAM.

CROSS SECTION OF EARTH DAMS FOR SEROS CANAL.

PROPOSED FAYON DAM

GENERAL CROSS SECTION.

HYDROELECTRIC DEVELOPMENT OF THE NOGUERA-PALLARESA, SEGRE & EBRO RIVERS.

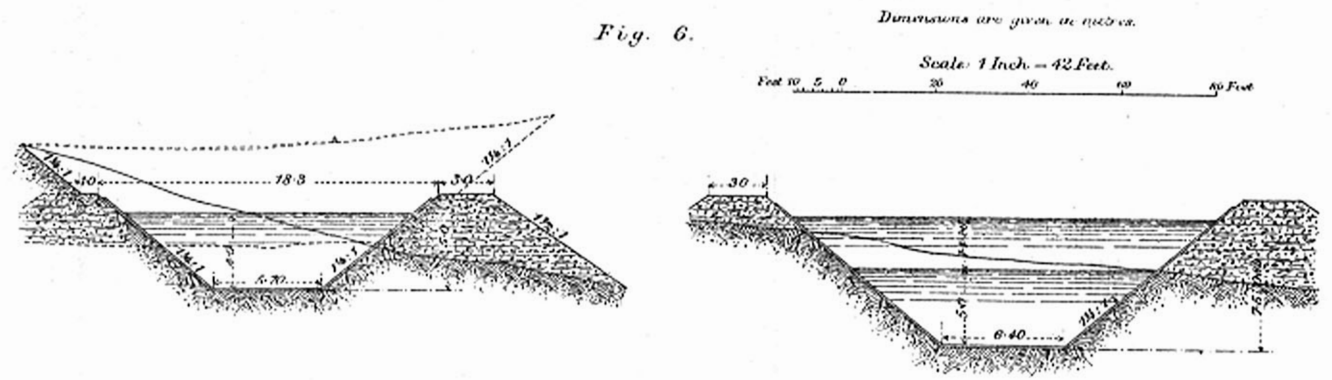


GENERAL CROSS SECTION.

TREMP POWER HOUSE.

Proportion of Cement, used at different points of Dam in lbs. per cubic yard of Concrete, and % of weight of one cubic yard of Concrete Av. Spe. Gravity of Concrete 2.40.

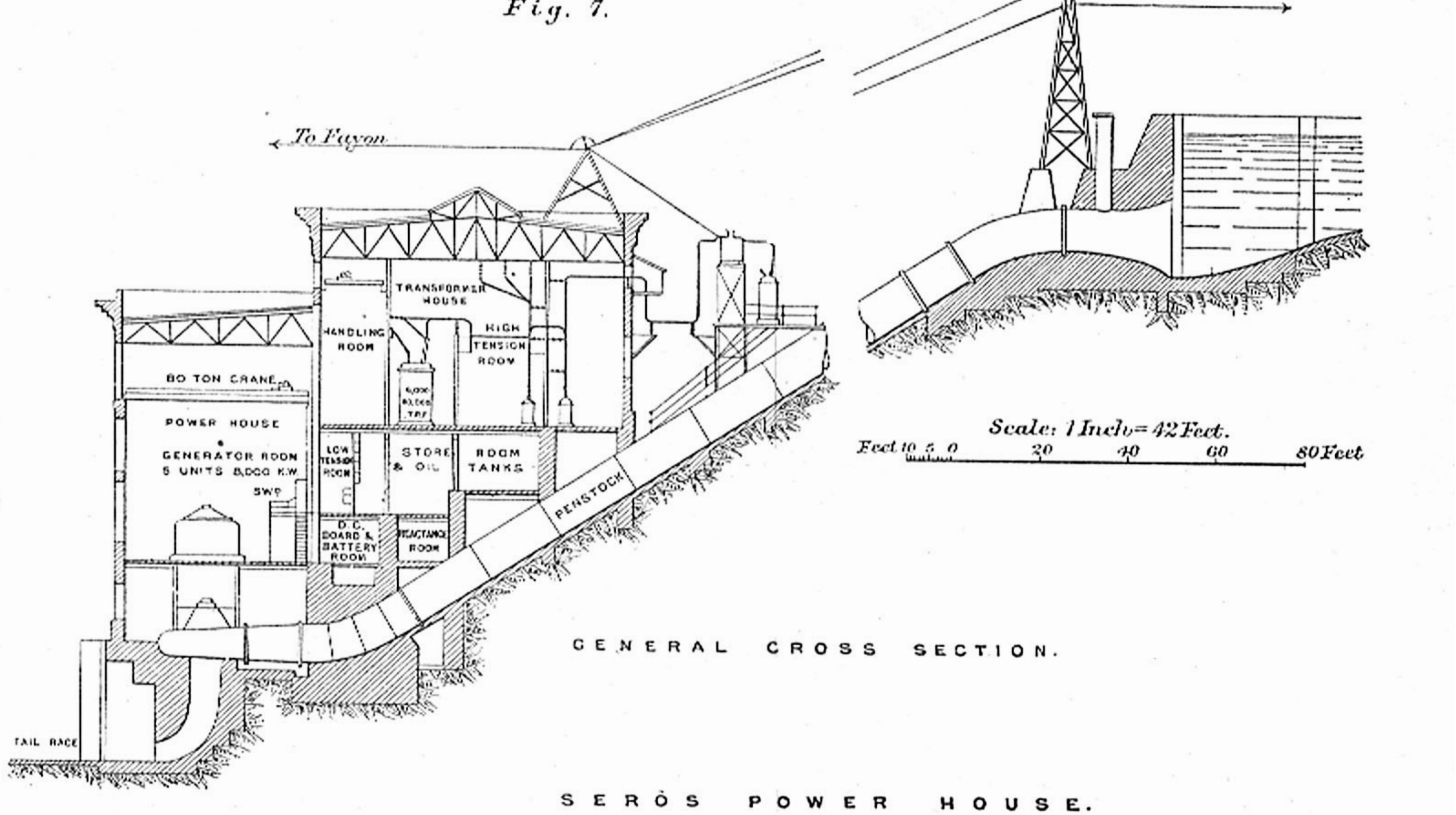
DIAGRAM SHOWING DIFFERENT PROPORTIONS OF CEMENT USED IN TALARN DAM



CROSS SECTION AT UPPER END.

CROSS SECTION AT LOWER END.

SEROS CANAL.



GENERAL CROSS SECTION.

SERÓS POWER HOUSE.

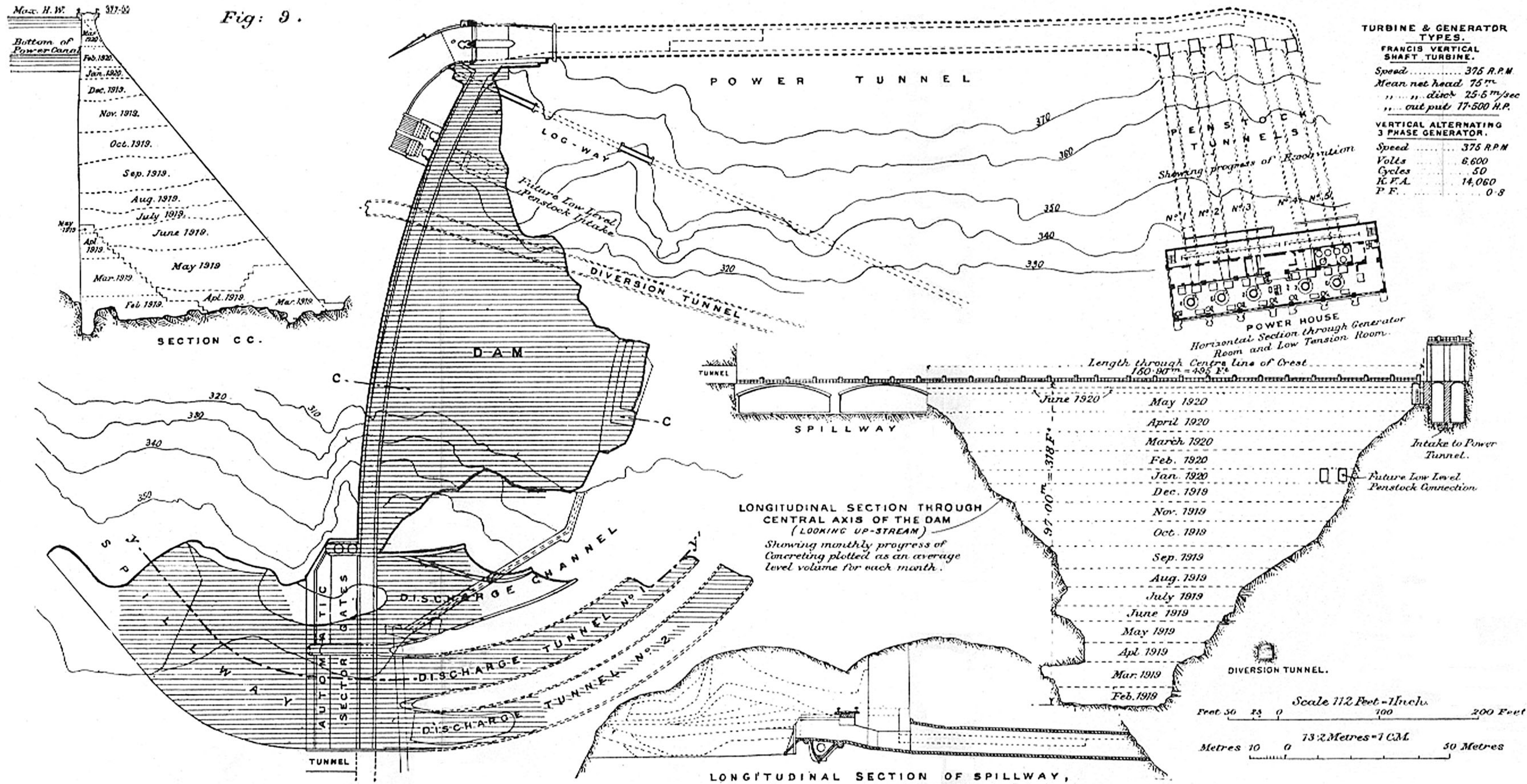
H. F. PARSHALL.

Waterlow & Sons Ltd., late Thos. Kell & Son, London.

HYDRO-ELECTRIC INSTALLATIONS OF THE BARCELONA TRACTION LIGHT AND POWER COMPANY.

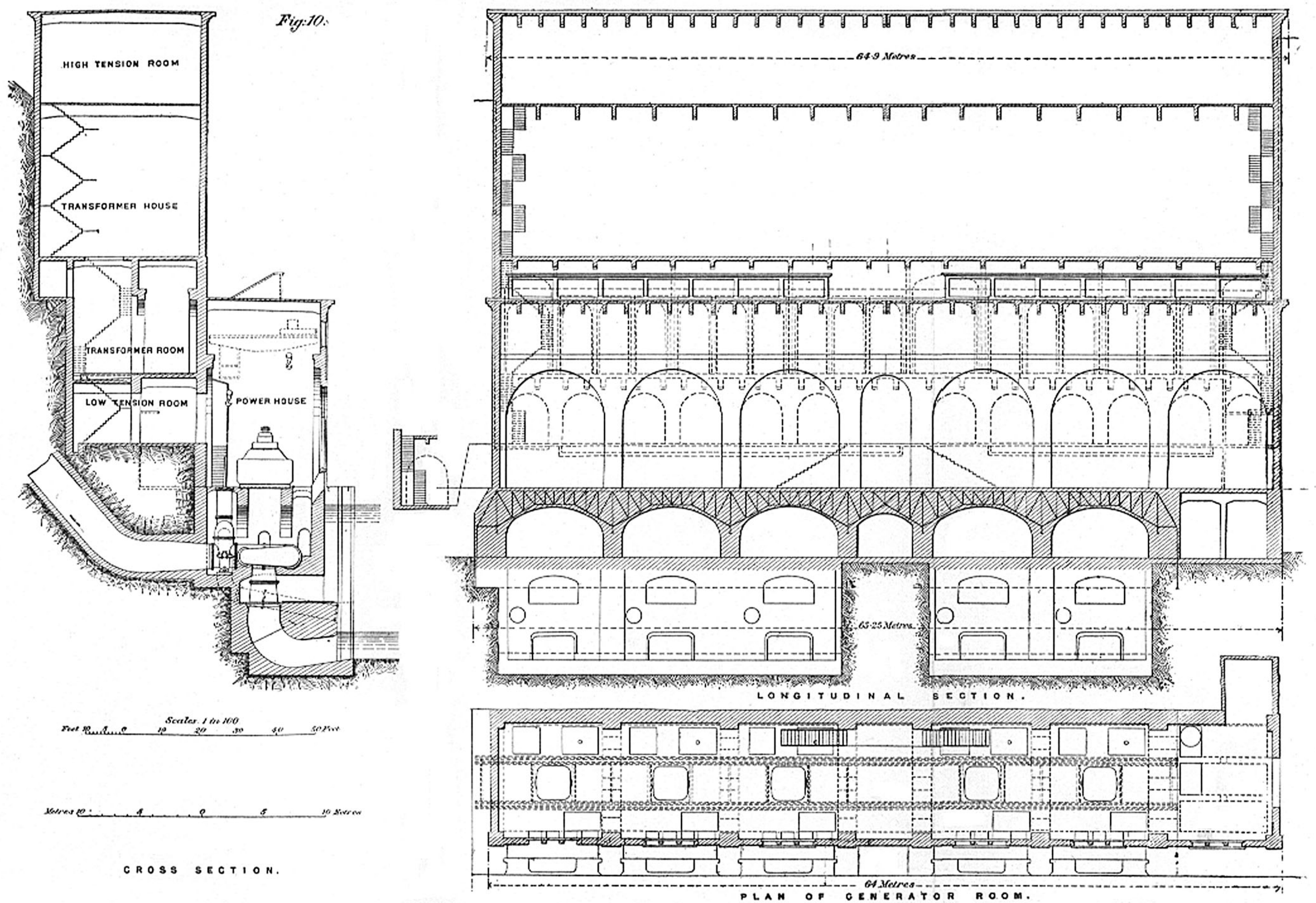
PLATE 3.
BARCELONA
HYDRO-ELECTRIC INSTALLATIONS.

Fig: 9.



ARRANGEMENT OF CAMARASA POWER HOUSE, CANAL, PENSTOCKS, AND OF RESERVOIR & DAM.

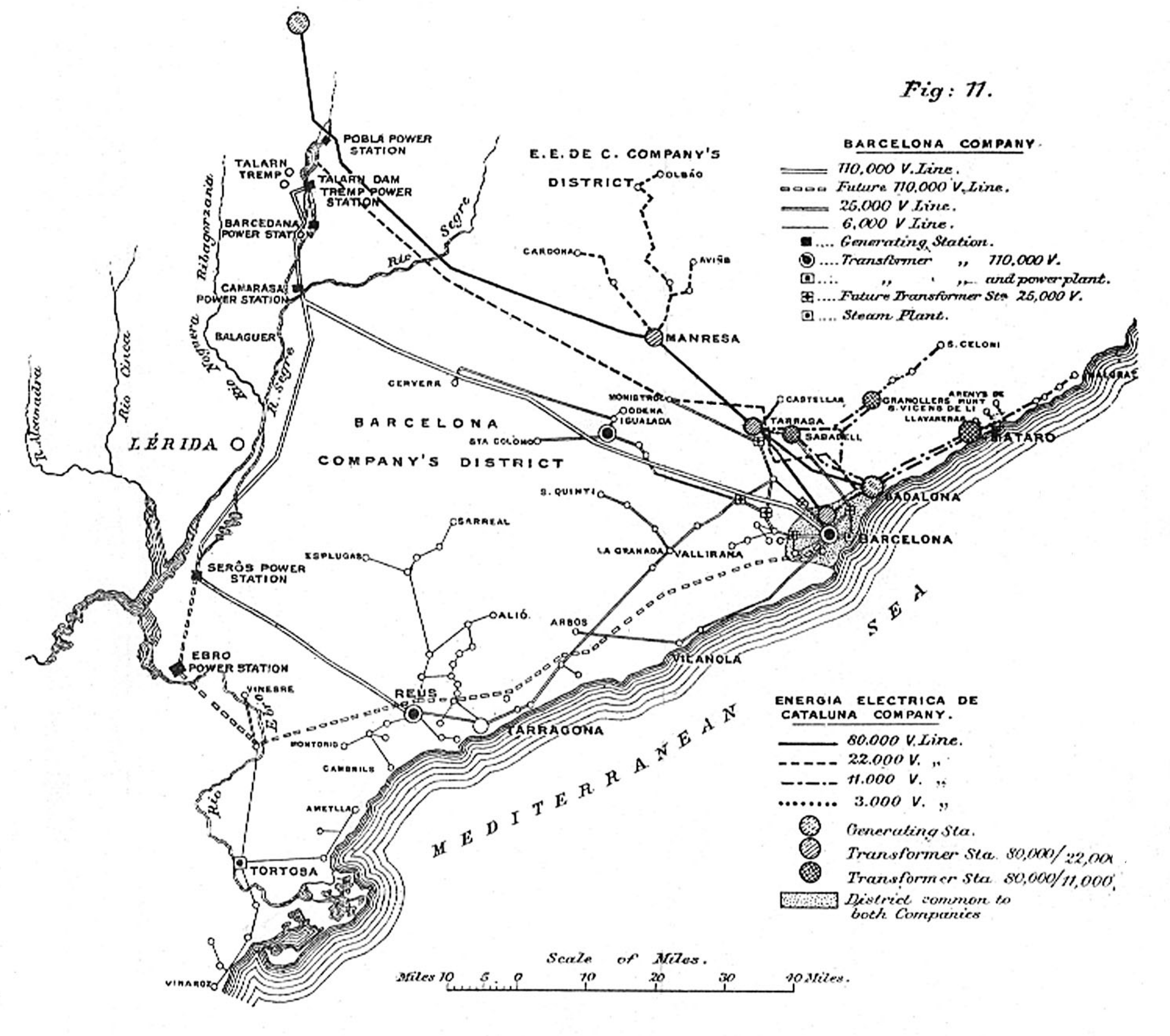
Fig: 10.



CROSS SECTION.

CAMARASA POWER HOUSE

Fig: 11.



ROUTES OF OVERHEAD TRANSMISSION LINES.

WATERLOW & SONS LIMITED, LATE THOS. KELL & SON, LONDON.