No. 1851

NEW DEVELOPMENTS IN HYDROELECTRIC POWER-PLANT DESIGN

By J. A. Sirnit, Birmingham, Ala.
Member of the Society

The most logical and simplest way to maintain the full capacity of a hydraulic power plant during flood periods is to remove the high tail water from the discharge opening. This may be most successfully accomplished by a backwater suppressor utilizing the waste water and the present paper is chiefly devoted to the development and application of this method.

Two testing models are described and the results presented, while the design of the draft-tube orifice is discussed at considerable length. Finally the plant of the Alabama Power Company at Mitchell Dam on the Coosa River in Alabama, where the Thurlow type of backwater suppressor was first conceived and applied, is described, details of its construction and equipment being included.

With the rapid development of industry calling for more and cheaper power, and with the increasing cost of steam power, greater interest is being shown in water-power developments all over the world.

2 In this country and abroad hydroelectric developments are being made on a scale never experienced before, and plants are being built and generating units installed in sizes that would have been astounding but a short while ago. Economy in design and efficiency in operation have become factors of great importance, and the designing engineers of hydroelectric power plants are striving to improve the efficiency of the power plant with the same keenness which the designers of the steam-electric power plants have manifested for many years past.

3 Just as the designer of steam plants endeavors to produce the most power out of a pound of coal, so the designer of hydroelectric plants is anxious to utilize every drop of water and con-

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Presented at the Spring Meeting, Atlanta, Ga., May 8 to 11, 1922, of The American Society of Mechanical Engineers.

vert it into useful power with the minimum loss, and for the least cost.

4 The designers of water wheels and turbines have helped a great deal by improving the efficiency of the driving machinery; the designers of the generators have done likewise and these machines have well-nigh reached the maximum possible point of perfection.

5 A great achievement was attained in recent years by the hydraulic engineer with the improvement of the draft tube, which has helped very materially to increase the efficiency of the power plant. With the introduction of White's hydraucone, Moody's spreading draft tube, and other improved tubes, a distinctive mark has been set in hydroelectric power-plant design, and today we find the hydroelectric plant one of the most efficient power-producing plants.

6 But there are many power plants and possible sites for such plants where the supply of water is very irregular, and where, owing to the nature of the surrounding country, it is impossible to provide sufficient storage for the utilization of all the water flowing in the stream.

7 In many hydraulic power plants, now in operation or proposed, there is, or will be, a great loss of power annually, due to the fact that during flood conditions when water is being wasted over the spillway, the level of the water in the tail race at the outlets of the draft tubes leading from the turbines is raised, thus reducing the head on the turbines and in turn their capacity and the output of the power plant. There are many notable examples of these conditions, and in some cases reduction in effective head on the turbines becomes so great at times as to completely shut down the power plant. The Hales Bar plant on the Tennessee River is an example of where these conditions occur during the spring floods.

8 In many cases of proposed developments, engineers have hesitated in recommending the carrying out of the development on account of backwater conditions in the tail race, which can be foreseen and predicted very closely. The proposed development at the Great Falls on the Potomac, which has been under discussion for many years, represents an example.

9 Engineers for many years have wrestled with this problem and have tried to overcome this difficulty by installing a greater number of generating units where it was possible to do so, to com-

pensate for the loss in capacity of each unit; of course such a procedure necessarily makes the installation more expensive, with the resulting increase of production costs. Attempts have also been made to counteract this loss in head by admitting water into the draft tube through jets at a relatively high velocity which, by accelerating the velocity of the combined turbine discharge and jet water through the draft tube, produce a negative head which is added to the head on the turbine. A number of variations in the place and manner of introducing this jet into the draft tube have been tried and results published. But the results have not been entirely satisfactory.

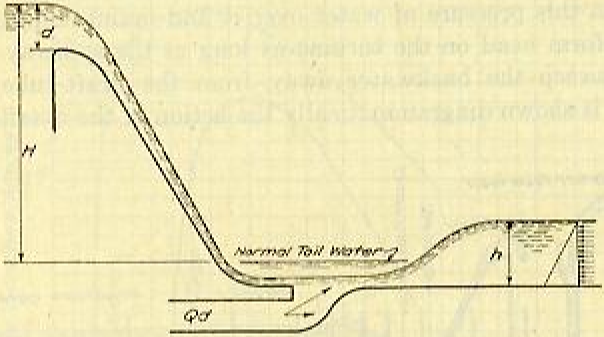

Fig. 1 Action of Spillway Water on Tail Water

(H = head above tail water; d = depth of water above spillway; h = total water column balanced; Qs = quantity over spillway; Qd = quantity through draft tube; Vs = velocity over spillway; Vd = velocity through draft tube; and w = weight of 1 cu. ft. water = 62.4 lb.)

10 The most logical and simplest way to maintain the normal head on the water wheel, and thereby the full capacity of the plant, during flood periods, is to remove the high tail water from the discharge opening, and credit is due to O. G. Thurlow, chief engineer of the Alabama Power Company, who conceived the idea of utilizing the waste water to accomplish this fact, thereby successfully solving the problem. The development of this conception resulted in what is now known as the Thurlow backwater suppressor.

THE THURLOW BACKWATER SUPPRESSOR

11 It is a well-known phenomenon that water flowing over a masonry dam having a downstream face of ogee section, leaves the apron in a thin sheet at high velocity. At a point below the

dam the water rises turbulently, forming a so-called "standing wave," "hydraulic jump," or "back roll." The thickness of this sheet and the velocity of the water depend upon the height and shape of the downstream face of the dam, upon the depth of water at the crest of the dam, and upon the quantity of water flowing over the dam. The energy developed in this thin sheet of water has generally been regarded heretofore as solely of a destructive nature, but in the backwater suppressor the energy of the spillway water is so directed as to remove the backwater from over the draft-tube orifice, sweeping it downstream, thus freeing the draft tube from this pressure of water over it and maintaining a practically uniform head on the turbine as long as the spillway water is able to sweep the backwater away from the draft-tube orifices. In Fig. 1 is shown diagrammatically the action of the overflow spillway water on the tail water. The energy of the spillway water not only removes the height of tail water from the draft-tube orifice, but even lowers the normal tail-water level to a predetermined depth.

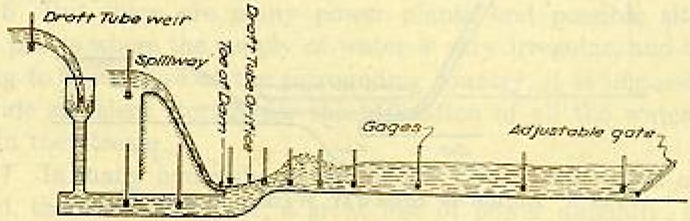

FIG. 2 DESIGN OF TESTING FLUME

TESTING MODELS

12 In order to substantiate the idea and evolve a definite theory on which to base the calculation, a model was constructed on a 1:24 scale at East Lake in Birmingham, Ala., where a small flow at 3 ft. head was available. The results obtained were so interesting that, to check the data obtained and to increase the accuracy of measurements, a second and larger model was constructed on a 1:10 scale at Jackson Shoals, Ala., where a greater flow and head were available.

13 The results obtained with the two models, when reduced to the same scale, were in close agreement and the observed results followed those calculated for similar conditions.

DESCRIPTION OF MODELS

14 Fig. 2 shows diagrammatically the essential elements of these models. Each consists of a forebay for stilling the water, a spillway having the usual ogee section, a draft tube with its orifice located directly under the spillway, and a tail-water wasteway.

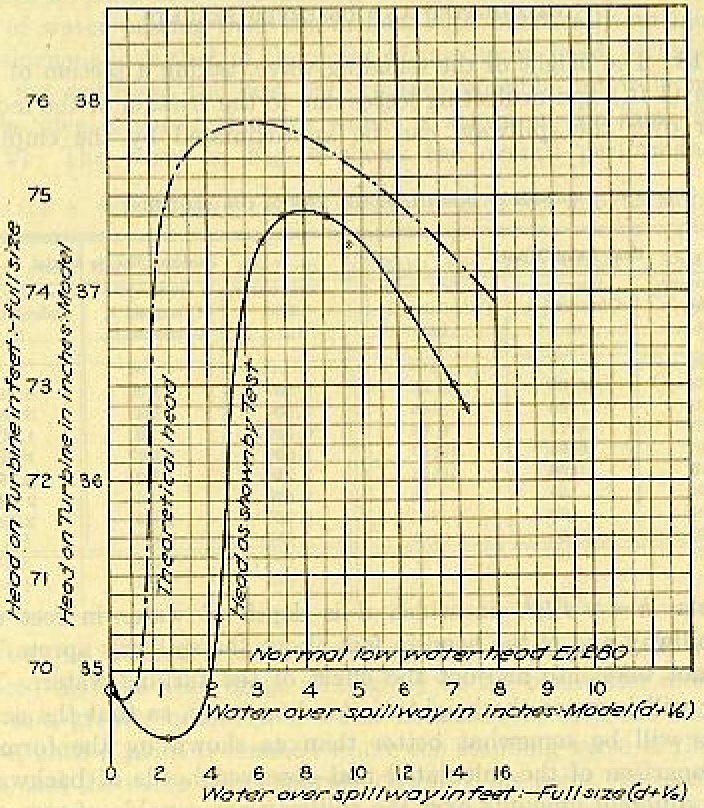

Fig 3 East Lake Head Curve

15 The height of the water in the forebay, wasteway and draft tube were measured in glass gages conveniently located on central platforms. By means of these, measurements corresponding to the pond-level head above the river bed, the effective turbine head, the depth of water over the spillway, and the backwater head could be conveniently determined.

16 Weirs were used in admitting water to the draft tube so

water over the spillway of the East Lake model is shown in Fig. 3. It should be noted that very small amounts cause a decrease in head because sufficient velocity has not been given to the draft-tube water to cause a thinning of the sheet over the draft-tube orifice, but when the ratio of spillway to draft-tube water increases to about one to one the curve takes a decided course upward and reaches its peak and starts falling off again due to a greater quantity of water passing over the orifice, with practically no increase in velocity above that of the point of maximum head. This curve does not represent the best performance possible but it is typical of the ideal theoretical curve which is shown in the same figure.

21 The curve in Fig. 4 shows the overall performance of the test as compared to that without the suppressor. It will be noticed that the head drops off slightly as the backwater increases, due to a greater quantity of water necessary to hold the standing wave, until a point is reached where the standing wave is 13.26 in. high, and the curve turns sharply down. This point represents the critical stage or the maximum height of backwater capable of being suppressed by a given amount of spillway water. This could be increased by having a design of spillway permitting a greater discharge.

TABLE 2 SUPPRESSING PERFORMANCE OF JACKSON SHOALS MODEL

Water over river bed, in.	Head without suppressor, in.	Head with suppressor, in.	Water over river bed, in.	Head without suppressor, in.	Head with suppressor, in
0	96	....	24¾	71½	88
½	95½	96½	26	70	87
2¼	95¼	95¾	27½	68½	80
19	77	96¾	29	67	73
20¼	75¾	96½	29¼	66¾	74
21½	74½	97	30¼	65¾	73
22	74	96½	34	62	68¼
22¼	73¾	96¼	35¼	60¾	66
22¾	73¼	96¾	40½	55½	66¾
23¾	72¼	96½	46	50	56½
24½	71¾	89½	....	....	....

22 Even after this point is reached a substantial increase in head is obtained, and at the last point plotted, with backwater 50 per cent of the total head, an increase of 5 in. is recorded. Fig. 5 illustrates the condition of backwater after the critical stage has been passed.

DESIGN OF DRAFT-TUBE ORIFICE

23 Several shapes of draft-tube orifices were tested. That shown in Fig. 6 leaves very little to be improved upon for getting a maximum height of standing wave and a maximum head on turbine. This design can be modified to give a greater head on the turbine but only at a sacrifice in the height of the standing wave.

24 The location of point x is of great importance as it controls the increase in head on turbine, and its relation to the elevation and angle of discharge of the spillway apron must be very exact or a poor performance will result; also consideration for the turbine "run-off" during the period when the suppressor is not in action must be kept in mind.

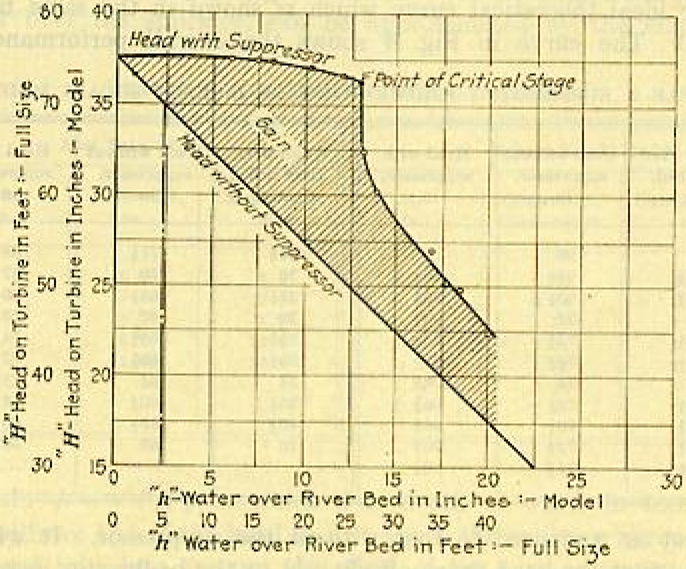

Fig. 4 East Lake Performance Curve

25 The length of tangent t must be such that it will direct the spillway water well along the line ab, and it should be at least 5 ft. for heads up to 25 ft. and 7 ft. to 10 ft. for heads varying from 30 to 100 ft. The amount of water flowing over the spillway will cause this length to change, but for depths up to 15 ft. this range will hold good.

26 The distance out of point x is determined by the amount of water passing through the draft tube. The area of the draft-

tube orifice subject to the action of the sheet of spillway water must be proportioned so that a back pressure in the draft tube is not necessary to force the two waters to mix. The curve of R_3 is great enough so that the centrifugal force of the fast-moving sheet of water will not cause it to leap clear of the concrete surface. R_2 makes a smooth transition, connecting point x and R_3 and is about $\frac{1}{2}$ R_3.

27 The standing wave is held out just beyond tangent R_3. The total distance from the lip of spillway apron to the point of wave must not be greater than good design of the other features will permit, as the friction of the high-velocity water diminishes the height of the standing wave, thereby causing a greater amount of waste water necessary to operate.

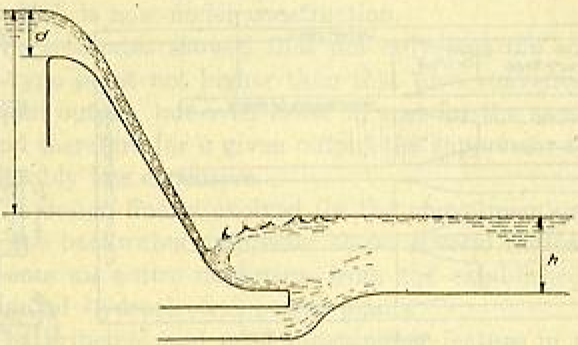

Fig. 5 Flood Conditions of Model

28 The river channel below tangent R_3 must be finished with neat concrete for a distance of four heights of the standing wave, in the case of heads up to 25 ft., and five to six heights for heads varying from 30 to 100 ft. This is necessary for good performance although a rough bed or water pocket can be used, but a great waste of water is required and heavy undercurrents, due to an imperfect standing wave, might scour the river bed badly or undermine the protecting apron.

29 This is of great importance if the rock strata are poor, as open seams will allow the high static pressure beyond the wave to be transmitted back under the protecting apron causing an uplift. This uplift must be given attention even when the apron is carried out to the desired point and provision made for its secure anchor.

DIVIDING WALLS

30 Each unit must be provided with dividing walls to prevent the water from coming in on the sides and to allow any one unit to operate independently.

31 The correct height and length of these walls is determined by the backwater and discharge curves of the river at the location of the power house. Section *A-A*, Fig. 6, shows the condition for the installation of four units. The three intermediate walls are at an elevation shown by the backwater curve when the required amount of water to operate four turbines and three suppressors is passing that point. When the fourth suppressor is brought into action the condition is as shown by the dotted line in unit No. 2, and these walls simply act as a guide to hold better conditions at the point of wave and prevent surging.

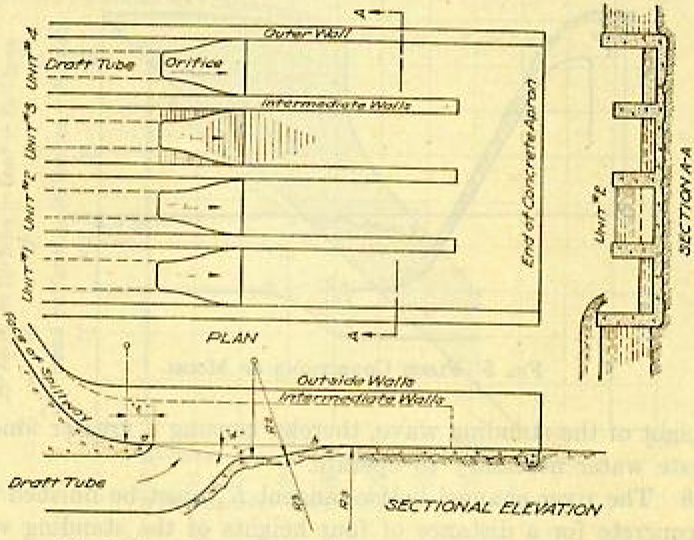

Fig. 6 An Excellent Design of Draft-Tube Orifice

32 The two outer walls are designed for extreme flood conditions, as any water passing over the walls into the suppressor sheet will cause a loss in head on the turbine and in height of standing wave. However, if there should be spillway gates on both sides of the power-house section equal to the width of two units, it need not be at the maximum high-water elevation but at the

stage shown by the combined discharge passing the power house and side spillway. This is due to the fact that although a perfect standing wave is not formed at the toe of the side spillways, a lower elevation is created than will be further down stream, where the true backwater elevation is measured.

POWER PLANT WITH BACKWATER SUPPRESSOR

33 Encouraged by the splendid results of the model tests and the economic advantages of the undertaking disclosed by careful analysis, the Alabama Power Company decided to apply the backwater suppressor at Mitchell Dam on the Coosa River in Alabama, which is now under construction.

34 The estimates showed that not only was the cost of the suppressor-type plant not higher than that of a conventional-type plant of equal output, but even lower in cost for the same number of units, and therefore for a given output the suppressor-type plant was considerably less expensive.

35 The design finally evolved for the above-mentioned power plant with the backwater suppressor shows several radical changes and represents an entire departure from the established conventional design of hydroelectric power plants.

36 The principal and most outstanding feature in this plant is the location of the power units on separate foundations in the river on the upstream side of the dam (Fig. 7). Although this was not necessarily the only possible way to build the power house, it was the most economical. The river at this point being comparatively narrow, the entire length of the dam was required for spillway, and since the prime requisite of this type of plant is that the draft tube discharge directly under the spillway section, the units had to be so located that they would not obstruct any part of the spillway section.

37 The individual and separate power-house units offer the added advantage that trash racks do not present a solid front, which helps materially in cleaning them and affords an easy and convenient way of diverting the trash past the power house and over the spillway.

38 The usual power-house building is entirely eliminated. The generator room is covered with a low roof, which is designed in two sections, joined on the transverse line, mounted on rollers; each section moving in opposite direction. In normal operation the

generator room is completely protected from the weather, but for handling large parts of the machinery, this roof can be opened and a crane utilized for performing the necessary work.

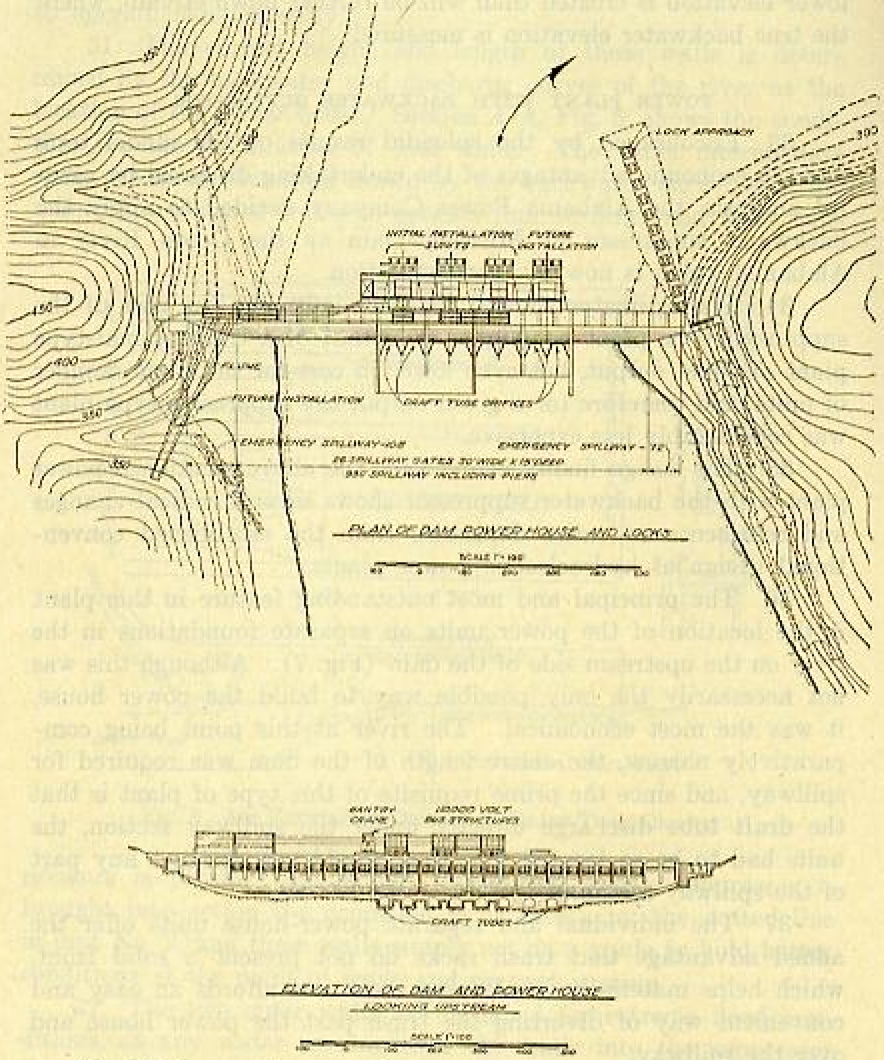

Fig. 7 General Plan and Elevation of Dam and Power House

39 A single gantry crane (Fig. 7) with full travel over the entire length of power-house section is so designed that everything, with exception of spillway gates, can be handled by this crane. It

is equipped with one 125-ton and one 20-ton hook, the former for handling heavy machinery and the latter for raising and lowering penstock gates, handling racks, stop logs and all other lighter parts.

40 An outdoor transformer and high-voltage switching station is located on the bridge over the spillway (Fig. 8). This plant is designed for operation on unit system, i.e., the generator and its bank of step-up transformers are connected as a unit and all principal switching is to be done with the high-voltage circuit-breakers. In stations where units are of large capacity, as in the plant under discussion, (20,000 kva.) the unit system is very economical and preferable, as it presents the simplest, yet sufficiently flexible, form of operation.

41 The entire operating floor is on one floor level. The generators, governors, switchboard, low-tension switches, bus galleries and offices are easily reached without climbing stairs or ladders. This materially adds to the convenience of operators and makes the supervision and inspection of the plant more effective. This feature of providing easy accessibility to all important parts of the station is very frequently lost sight of by power-house designers and the lack of these conveniences has been the cause of inefficient operation or even of breakdowns, due to the fact that operators have neglected the equipment to a lesser or greater degree.

42 The generators are so installed that the hot air from the generator is discharged into a separate compartment under the main floor and is expelled into the atmosphere through side openings of that room in summer time, thereby keeping the generator room reasonably cool. In winter, however, when heat in the rooms is desired, the outside openings can be closed and through registers in the floor the warm air enters the generator room.

43 The penstock does not represent a true scroll casing but rather a combination of scroll effect and open flume. The water velocities in the penstock being low, approximately 4 ft. per sec., this combination affords a better design.

44 The location of power-house units on the upstream face of the dam lengthened the discharge tunnel to about 120 ft. in length from the center line of the unit. Although the velocity of the discharge is only 4 feet per sec., the effect of this long column of moving water had to be carefully investigated and studied. This problem was solved satisfactorily by increasing the governor

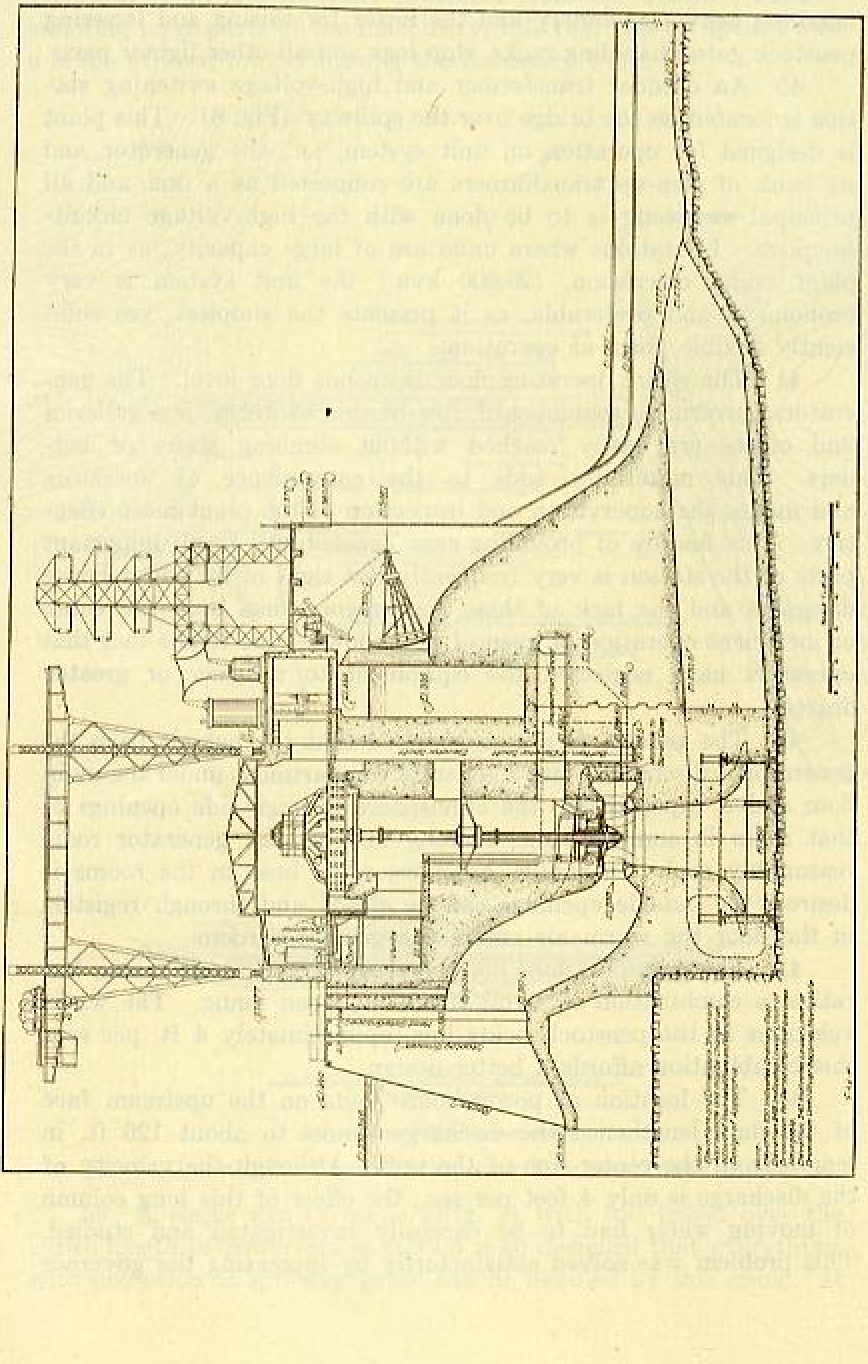

FIG. 8 CROSS-SECTIONAL ELEVATION VIEW OF THE POWER HOUSE

action to 3½ sec. and setting the turbine to the lowest practical level. Turbine settings always should be as low as possible, especially where improved draft tubes are employed. Many of the troubles in existing power plants, such as pitting of runners, excessive vibration, etc., can be directly traced to high wheel settings, particularly with high-specific-speed runners.

45 Fig. 7 shows that 26 spillway gates of the Tainter type are provided, each 15 ft. high and 30 ft. wide. These gates are capable of passing the maximum flood water known to have existed in the past. There are also six bays, two on the east and four on the west end of the dam, which are designated as emergency spillway openings. The crest of these openings is level with the top of the spillway gates and their function is to provide additional spillway capacity in case of unprecedented floods when water would rise above normal pool level.

46 Although little has been said about the electrical equipment, it is one of the most important parts of the installation and should always receive close study and serious consideration if economical and efficient operation is expected.