A REPORT ON THE PROGRESS OF CONSTRUCTION OF LITTLETON DEVELOPMENT

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Description and History

The Connecticut River is born amid trout pools and beaver dams in three lakes at the extreme northern tip of New Hampshire, almost at the Canadian border. These bear the unromantic names of First, Second and Third Lake, and the first two have been raised by the New England Electric System to impound 88,000 acre feet of water. A fourth artificial lake was formed just downstream of these by the completion of the Murphy Dam in Pittsburg, New Hampshire, by the New Hampshire Water Resources Board in 1940, and this when full adds an additional 100,000 acre feet to the storage. From Third Lake to the mouth of the river over four hundred miles away, the Connecticut drops twenty-two hundred feet to the sea, but before arriving there it turns countless wheels and lights innumerable homes through the power generated by its falling waters.

A glance at the profile (figure No. 1) of the river gives some conception of the completeness of its development for power purposes. The total installed capacity of the power stations on the main stream including the Littleton Development which I will discuss today will amount to approximately 530,000 kilowatts and if the tributary streams are included the installed capacity will total about three-quarters of a million kilowatts.

For the first eighty miles from its headwaters at Pittsburg, the Connecticut drops steadily and uneventfully, but beginning at Dalton, New Hampshire, there is a succession of rapids extending almost twenty miles which with typical understatement the natives called Fifteen Mile Falls. In this stretch the river falls some 340 feet. This region had long been recognized as having great power possibilities but down through the years it remained unused except for a comparatively small industrial power development at the upper end of the

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rapids at Gilman, Vermont, and another near the foot of the rapids at McIndoes, Vermont. During the first quarter of the present century numerous studies were made for various owners in an attempt to design a feasible power development for use either at the site or within reasonable transmission distance. However, the characteristics of both the site and the river made impractical the development

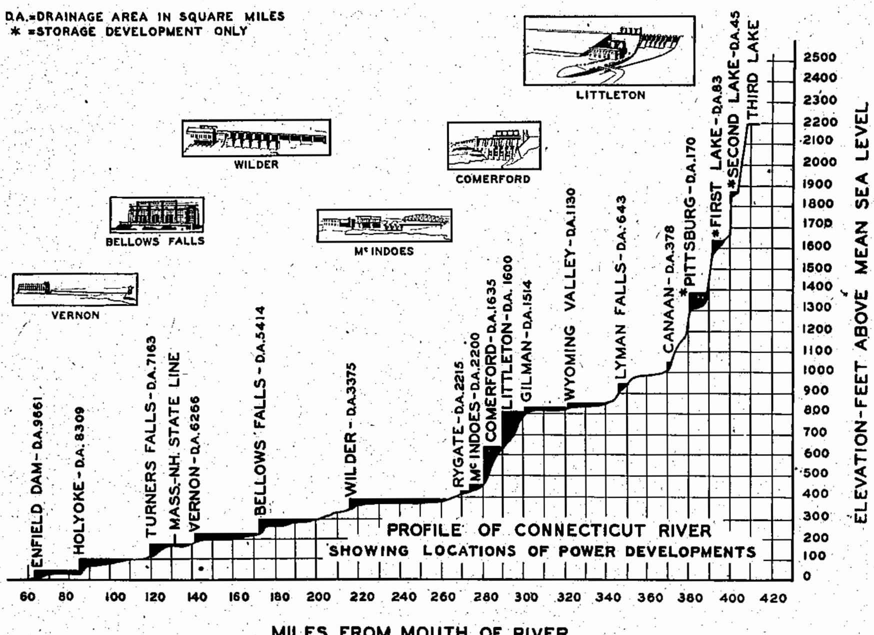

FIG. 1.—PROFILE OF CONNECTICUT RIVER.

of these powers for use in local industries and small utility systems alone.

The New England Electric System, meanwhile, had completed in 1909 a hydroelectric development on the Connecticut at Vernon, Vermont, and during the next twenty years it was successfully demonstrated that the most economical power for New England was obtainable from an interconnected power system including both tidewater steam plants and inland hydroelectric stations.

By the late twenties our power system had developed most of the feasible sites on the Deerfield River and had acquired extensive steam electric resources in southeastern New England. It was apparent even then that hydro power realized its greatest worth when designed to serve the so-called peak loads of the power system and it was at that time that the Fifteen Mile Falls properties were acquired and their development as peak load plants began.

In 1930 the lower section of the falls was harnessed by the completion of the Comerford hydroelectric station with an installation of

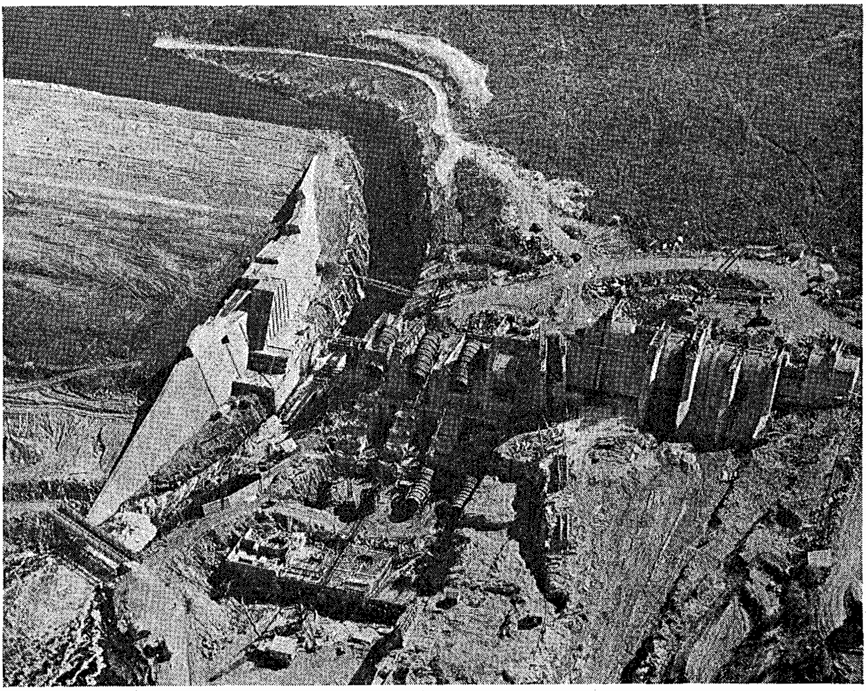

FIG. 2.—LITTLETON DEVELOPMENT—AERIAL VIEW.

150,000 kilowatts, and the Littleton Development (figure No. 2) now under construction at the upper end of the Comerford Pond will complete the utilization of the potential power in this region.

We are now concluding the third year of active construction of the Littleton Development which will be completed in 1956 and dedicated as the Samuel C. Moore Hydroelectric Station. The development will have power capacity identical with the Comerford Station and like Comerford, is designed to serve the extreme peak loads of a large interconnected power network. The development will require over 12,000 cubic feet per second of water when operated at nominal capacity with a full pond. With 1600 square miles of drainage area at the site such a flow is continuously available only during freshet conditions on the river, at which times the plant will operate more or less continuously as a base load plant. During drier periods the plant will normally generate power only a very few hours each day during the peak load hours on the system.

The dam site is located in the townships of Waterford, Vermont and Littleton, New Hampshire, with the river here forming the boundary between the two states. Littleton, New Hampshire, and St. Johnsbury, Vermont, are the largest nearby centers.

Geology

At the site, bed rock outcrops on the New Hampshire shore and continues at or near the surface up the hillside along the axis of the dam. Under the river, however, the bed rock descends rapidly and beneath the Vermont hillside it lies about 90 feet below river level and up to 200 feet below ground surface. Above the ledge in this area the overburden consists of quite impervious glacial till which in turn is overlain by a layer of sand and gravel.

The bed rock at the site was originally volcanic tuffs and lava which have been metamorphosed to a schist which varies from a massive rock with almost no cleavage to a slaty rock with highly developed cleavage. Excavation has revealed that in certain areas the rock has been subjected to punishment possibly by glacial action and had been quite badly shattered. Rock of this nature has generally been removed.

General Layout

The general layout (figure No. 3) of the development called for a large rolled earth dam on the Vermont side and across the river about 2040 feet long and 180 feet in maximum height, a 120-foot high retaining wall set on ledge above the New Hampshire bank, a concrete non-overflow section, approximately 180 feet in maximum height and 115 feet long which spans the channel excavated to divert the river during construction and in which final closure was made, a concrete intake structure 255 feet long and a concrete spillway section 373 feet long, containing a skimmer gate and three tainter gates flanked on each side by two bays of stanchion flashboards. At the southerly end of the spillway there is a concrete structure 120 feet long extending into a small earth dam about 340 feet long. A concrete core wall, 40 feet long, will tie this structure to the earth dike. The total overall length of the dam is approximately 3150 feet or about six-tenths of a mile.

Full pond elevation will be 809 feet above mean sea level and normal tail water at elevation 650.

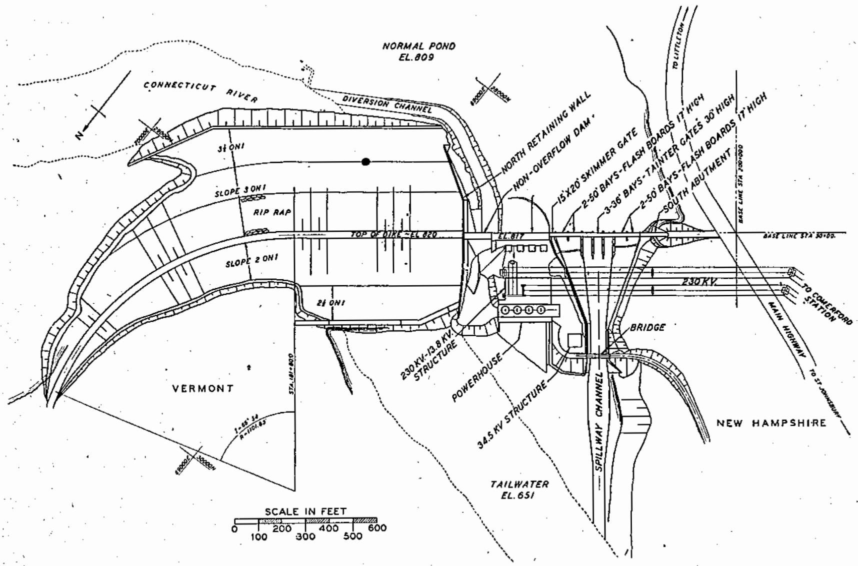

FIG. 3.—GENERAL LAYOUT.

The power house, situated downstream of the intake structure, contains four units, developing 150,000 kilowatts at a net average head of 149 feet. Water will be conducted to the turbines by four penstocks approximately 300 feet long and varying in diameter from 21′-6″ at the upper end to 16′-6″ at the scroll cases.

A tailrace excavated in ledge and earth will conduct the discharge back to the river. The spillway will discharge into a side hill channel excavated in ledge and earth with a training wall on the powerhouse side and a short training wall at the upstream end of the opposite side.

DIVERSION CHANNEL

The first major step in the actual construction of the development was the diversion of the river into an open channel on the New Hampshire side. This diversion channel (figure No. 4) was excavated during the latter part of 1953 and is 50 feet wide at the bottom, about 1600 feet long and 70 feet in maximum depth. Concrete side walls and piers slotted to take timber stop logs were provided in order to facilitate final closure.

Upon the completion of the diversion channel the river was turned from its normal course on December 20, 1953 by cofferdams

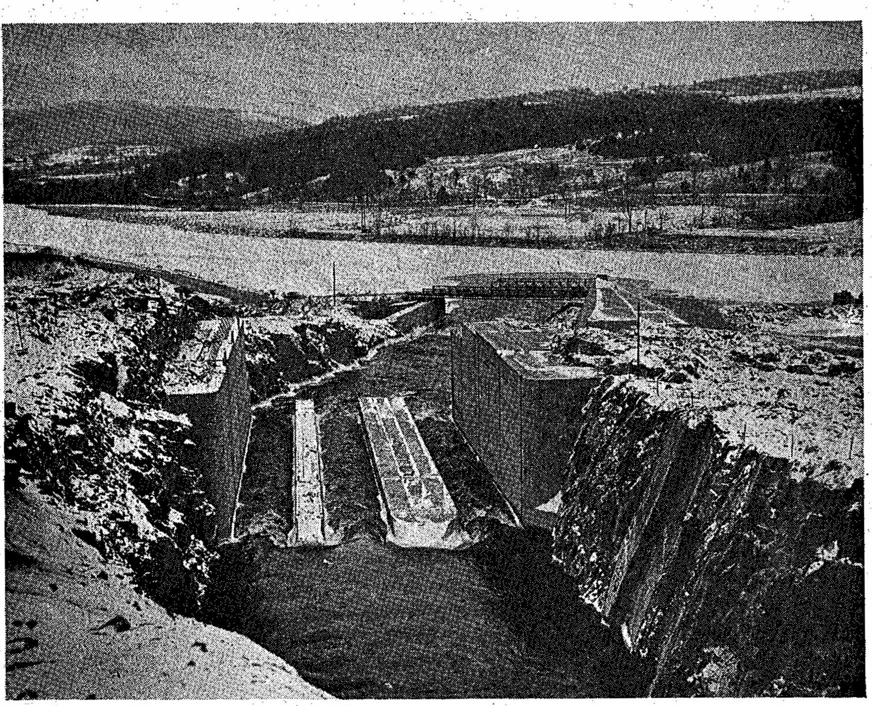

FIG. 4.—DIVERSION CHANNEL.

above and below the area to be occupied by the earth dam. These cofferdams are of the rock fill type with an impervious layer of boulder clay protected by a filter layer on the slope adjacent to the water.

At the New Hampshire end of the upstream cofferdam where the converging entrance to the diversion channel increases the velocity of the river flow, it was felt that difficulty might be encountered in blanketing the face of the boulder clay and consequently a concrete paving was placed in that area to aid in sealing the cofferdam.

We were of course taking a calculated risk in diverting the river before the passage of the spring runoff high water since it was economically impractical to build the cofferdams high enough to withstand the maximum spring flood that might occur. However, they were built to withstand a runoff that was normally exceeded only 25 per cent of the years of record and we felt that if we did not get an exceedingly high spring flood we would thus gain several weeks of valuable time for preparing the foundation of the earth dam.

Actually we lost our gamble, since in April of 1954 the river rose to 35,000 c.f.s., the fourth largest flow on record, and our cofferdam was breached. However, it was quickly repaired and we were able to unwater the site of the earth embankment at least as quickly as if we had delayed diversion until the spring runoff had ended.

Later the cofferdams became a part of the permanent rock toes of the dam.

By contrast, in the spring of 1955 we had a great deal more to lose in the event of a major flood and every possible precaution was taken to be sure that we could safely handle the maximum amount of water which we could conceivably receive. The earth dam was brought up to a height which would accommodate more than twice the largest flow we had ever had and a timber crib, reinforced with steel sheeting, and a concrete flood wall were provided on the power house side of the diversion channel. Our highest runoff amounted to 27,000 c.f.s. in 1955 and it was passed without incident.

Earth Embankment

After the area between cofferdams was unwatered in May of 1954, the river bed was stripped of boulders and loose material and the top soil was stripped from the remainder of the embankment area. A wide trench was then excavated through the overlying pervious material to boulder clay.

It was unfortunate that directly across the river from the area of good ledge outcrop on the New Hampshire side, the overburden on the Vermont side consists of pervious material to a considerable depth. Only a short distance upstream, however, a good impervious boulder clay lies near the surface and extends downward to ledge. Because of this we have moved the Vermont end of the center-line as far upstream as possible while maintaining the New Hampshire end in the area of good ledge outcrop. This has made necessary a curve in the alignment of the dam.

The cutoff trench was excavated as far upstream as practicable, where the underlying impervious material lay at a more shallow depth. This trench was backfilled with boulder clay, compacted by rolling, which connects with an inclined core of boulder clay sloping back to the center of the embankment. The main body of the embankment consists of sandy till, a somewhat less impervious material and the outer faces consist of a shell of pervious sand and gravel.

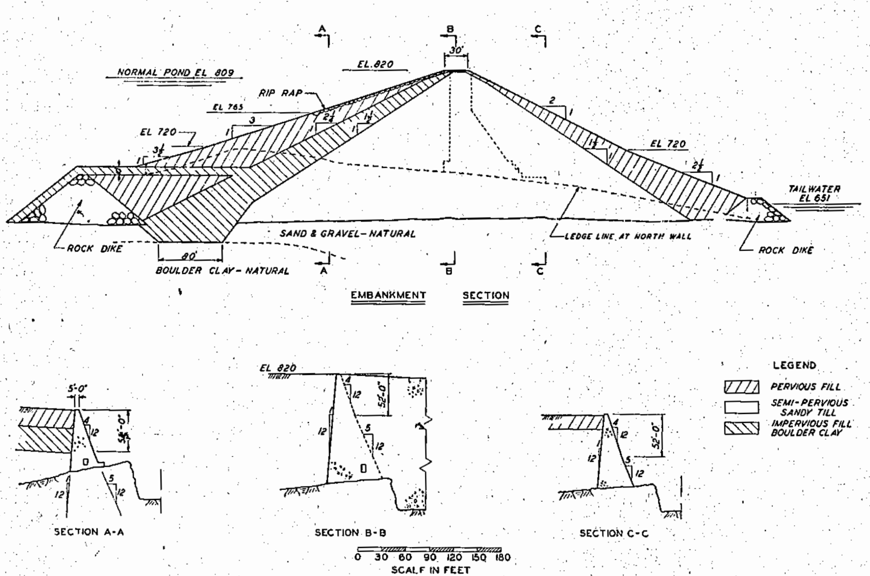

FIG. 5.—NORTH EMBANKMENT AND RETAINING WALL.

The embankment (figure No. 5) has a crest width of 30 feet at elevation 820 with slopes of 1 vertical on 3 horizontal upstream and 1 on 2 downstream for the upper 100 feet changing to 1 on 3½ upstream and 1 on 2½ downstream below that. The upstream slope was protected against wave action by riprap extending 55 feet downward from the crest. The toes of the dam consist of rock fill and filters to provide easy drainage and greater stability.

During stripping of the foundation, a deposit of varved clay was found in the Vermont bank downstream of the center-line of the embankment and extending to a point downstream of the toe. After analysis it was decided to excavate a large part of this material which could be conveniently reached. The remainder was contained by flattening the surface slope with rolled fill starting at the contour at elevation 720 and sloping down toward the river on a slope of 1 vertical on 4 horizontal.

Ample supplies of embankment material were found within a short distance from the site, the principal borrow areas being on the Vermont shore just upstream of the dam.

The embankment was completed in the Fall of 1955 and contains about 3,300,000 cubic yards of material.

Studies were made of the stability of the earth dam under the supervision of Professor D. W. Taylor of M.I.T. and piezometers were placed at various locations and elevations in the embankment and foundation in order to measure pore pressures. These consist of a well point set in a sand pocket which is sealed with grout against leakage from higher elevations, with a ½ inch wrought iron pipe extending to the ground surface. Water elevations in the pipe are read by means of an electric sounding device. Readings have been made at regular intervals, most of the piezometers showing some small fluctuation with tail water elevation. Only at one point has there been evidence thus far of appreciable pore pressure or discernible fluctuation with head water. This piezometer is located at the ledge surface immediately downstream of and below the cutoff trench. Readings in this piezometer indicate pressures amounting to approximately 50 per cent of the total head differential between pond and tail water. Stability studies were therefore renewed assuming the maximum pore pressures which the piezometer readings would lead us to consider possible and these have indicated no serious reduction in safety factor, largely because of the sloping core.

Compaction, shear, and permeability tests were also made of the materials available for construction. During placement of the embankment, a field soils laboratory was set up and numerous field compaction control tests were made, one density determination being made for each thousand yards of fill in the early stages of the work with this number being reduced as experience of the materials and equipment was gained. Mechanical analyses and optimum moisture content determinations were also made.

At the height of the embankment placing operations the equipment in use included forty bottom dump and rear dump Euclids, seven Euclid and six Caterpillar scrapers, 15 bulldozers, nine shovels and a huge fleet of trucks. Maximum yardage placed in a single day of two 10-hour shifts amounted to 32,000 yards and a maximum of 744,000 yards were placed in a single month.

Retaining Wall

The retaining wall which supports the embankment is of gravity section and extends 376 feet downstream and 400 feet upstream from the axis of the dam. Fifty-five thousand cubic yards of concrete were placed in its construction which was completed in August of 1955. A grouting and inspection gallery has been provided in the base of the wall, as well as in the intake, non-overflow and spillway structures.

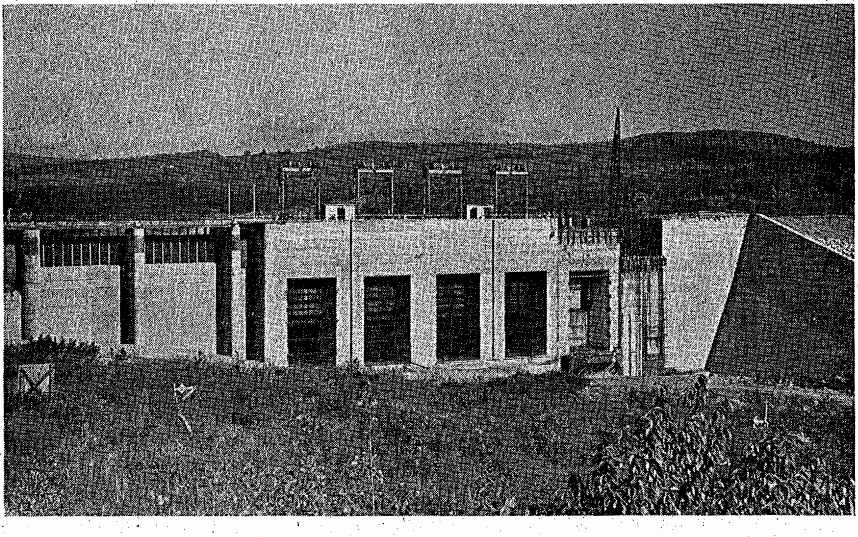

Fig. 6.—Intake and Non-Overflow Structure During Construction.

Intake and Penstocks

The intake (figure No. 6) is of gravity design and provides for four steel penstocks controlled at the upper end by wheel gates, 18 feet wide by 24 feet 3 inches high, with 60-ton electric hoists. The sills of the gates are at elevation 725 to permit plant operation under a 40-foot drawdown. The intake openings are provided with racks for the full height, composed of round edged flat bars, spaced 3 inches in the clear, and carried on steel supporting members. Racks and supports were designed for a ten-foot difference in head to allow for some clogging of the racks. A compressed air cleaning system has been installed and will be used in conjunction with a truck crane for handling trash.

The penstocks are located on 50-foot centers and weigh about 350 tons each. They are of all welded construction and are designed for a maximum stress of 13,750 pounds per square inch with 85% efficiency of welded butt joints. They were designed for the static head, plus a pressure rise above pond level varying from zero at the intake to 80 feet of water at the outlet end. To the thicknesses thus determined, one-sixteenth inch was added for corrosion, resulting in a total plate thickness of ⅝" at the upper end and $\frac{15}{16}$" at the lower. A hydrostatic pressure test was made on each penstock to 150 p.s.i. pressure at the lower end after which the penstocks were painted inside and out and an earth cover was placed over them to prevent ice formation.

A model of the intake was made at the Alden Hydraulic Laboratory of the Worcester Polytechnic Institute and numerous tests made to determine the best shape and dimensions for the approaches to the penstocks.

Spillway

The spillway dam located on the New Hampshire river bank is 373 feet long and from 40 to 100 feet in height (figure No. 7). A bridge has been built over the crest and its piers reduce the net length of the spillway to 323 feet.

The skimmer gate, 15 feet wide by 20 feet high, is located next to the intake. It is mounted upstream of a concrete ogee section with its crest or gate still at elevation 789. This gate is of the dropping type and is controlled by an electrically operated, motor-driven double stem screw hoist. Its primary function will be passing the debris which may collect in the head water pond.

Next in the spillway are two bays, each 50 feet long, of stanchion type flashboards, 17 feet high, with a six-foot pier between bays. The crest in these bays is at elevation 792 with profile designed for an overflow of about 21 feet. The stanchion flashboards consist of vertical steel beams on about 5-foot centers with horizontal timber stop logs between beams. The bottoms of the beams are set in sockets in the concrete crest and the tops are attached to the bridge structure and so constructed that they can be readily released by one man in case of emergency.

In the center of the spillway are three bays each with a steel tainter gate, 36 feet long by 30 feet high, with 8-foot thick piers at either side of the bays. The dam crest at the gates is at elevation 779 with its profile designed to give proper nappe conditions for overflows up to 36 feet deep.

Each gate has a fixed, electrically operated, motor-driven hoist and is provided with electric heating to prevent ice formation from

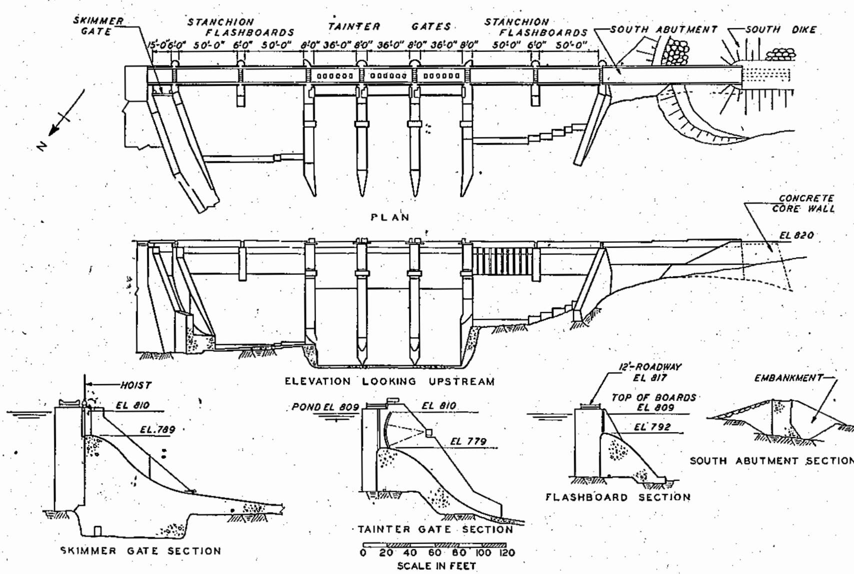

FIG. 7.—SPILLWAY—PLAN, ELEVATION, AND SECTIONS.

interfering with its operation. In addition, a compressed air bubbler system prevents ice from forming in the water in front of the gates. An auxiliary power supply has also been provided to insure our being able to operate the gates even in the event of a power failure during flood conditions.

Proceeding southerly we next have two more 50-foot long bays of stanchion flashboards.

The spillway has a discharge capacity of about 120,000 c.f.s. with the pond level held at elevation 809 which will be normal pond elevation. This leaves 11 feet of freeboard. The generating units themselves will pass better than 12,000 second feet.

As contrasted with this total flood capacity, the maximum flood of which we have record in this vicinity was about 50,000 second feet in 1936. The tainter gates alone have a greater capacity than this, so that throughout the 55 years of record at no time would it have been necessary to remove flashboards.

The adjoining structure will be a concrete section, 120 feet long, extending into a small earth embankment with a central core of boulder clay. A 40-foot long concrete cutoff wall will serve to tie this structure to the earth dam. The earth dam here has a top width of 25 feet with slopes of 1 on 2 downstream and 1 on 3 upstream.

The spillway discharges into a rather long and steep channel in which it was obvious that we must expect very high velocities. We therefore had constructed at the Alden Hydraulic Laboratory a scale model of the entire spillway, powerhouse, tailrace, spillway channel and the river below the channel and tests were conducted upon this model continuously for over a year in order to study the problem of dissipating the energy in the water, reducing turbulence and preventing any harmful erosion, and to obtain the best possible design of all the components which made up the flood passing structures of the dam.

This model proved valuable in many ways and paid for itself many times over in economies we were able to effect through analysis of the test results.

The channel is about 1200 feet long and excavated in ledge throughout most of its length. It slopes toward the river at a 15 per cent incline.

As excavation proceeded there was some concern about the seamy condition of the ledge in the channel area and it was decided to pave the major portion of the bottom and sides of the channel with a minimum thickness of one foot of concrete.

At the lower end of the channel where it re-enters the river, the ledge drops off sharply and continuing the excavation to ledge through deep overburden or attempting to construct a stilling pool deep enough to create a hydraulic jump would necessitate a very substantial and expensive quantity of excavation. We therefore decided to excavate only a pilot channel through this area and let the water do our excavation for us over the years. The model studies have indicated that there is little tendency for the eroded materials to build up in front of the tailrace to affect tailwater elevation and the eroded material will be harmlessly deposited in the Comerford pond.

Power House and Hydraulic Equipment

The power house (figure No. 8) is of steel frame and brick construction on a concrete substructure. It is approximately 256 feet long by 52 feet wide with additional width of 25 feet below the generator floor and with a 20-foot wide extension upstream over the penstocks and beneath the transformer yard.

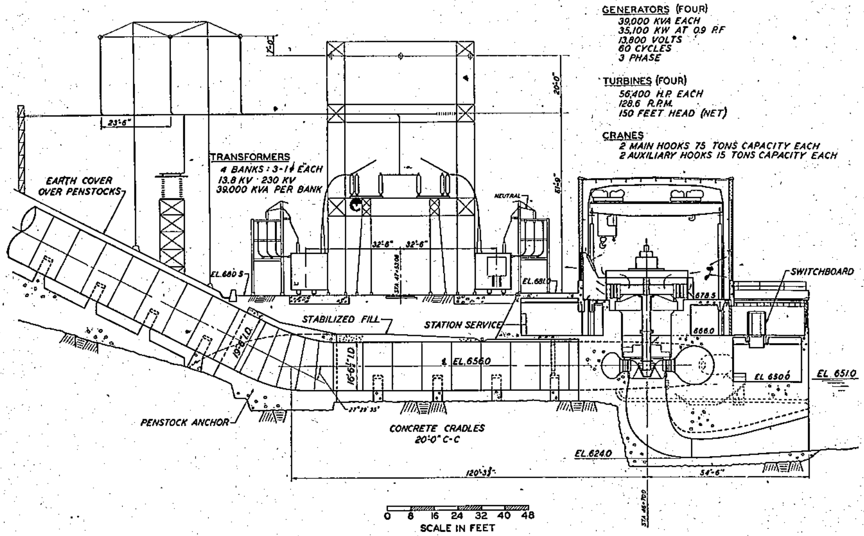

Fig. 8.—Powerhouse and Intake—Typical Cross Section.

The turbines and generators are located on the upstream side of the powerhouse with the switchboard and operating room downstream. The generator floor is at elevation 678.5, with the operating floor at elevation 666, and the basement floor at elevation 650.

Access to the power house is from a station yard at elevation 680.5 which is reached by means of a bridge across the spillway channel.

Panels of glass block and light buff brick of varying shades were used for the exterior of the superstructure to harmonize with the surrounding masses of concrete. The interior walls will be of light buff tile and red quarry tile will form the surfacing of the operating floor.

An extensive study was made of the relative merits of an outdoor, semi-outdoor or fully enclosed power house but we were unable to justify use of either the outdoor or semi-outdoor type either economically or from an operating point of view. Our studies of stations of these types, however, led us to rather a unique conception of power house design. Fundamentally, we have designed our power house as if it were to be one of the outdoor types with the control room, switchboard and all other appurtenances enclosed in the substructure below the generator floor level. This has resulted in making the superstructure merely a shelter for the cranes and generators. We thus eliminated the need for an expensive outdoor gantry crane, and for hatches or generator envelopes and at the same time provided shelter for men and equipment during periods of repair at a substantial saving in cost over a more conventional design.

The four turbines are vertical, single runner Francis type wheels of S. Morgan Smith manufacture, direct connected to the generators. Turbines are rated at 56,400 H.P. each and 3970 c.f.s. under 150 feet net head at 128.6 r.p.m. This is full load rating and therefore exceeds the requirements for normal operation at best efficiency. They will be set in plate steel riveted scroll cases which are connected to the welded steel penstocks. The draft tubes are formed in the concrete of the power house substructure with plate steel liners in the upper portion.

The turbine guide bearing will be of the babbitt lined, partially immersed, self lubricated type, with oil circulation provided by viscosity pumping action through grooves in the bearing shell. Oil from the immersion reservoir at the bottom of the bearing will be forced up the oil grooves by the rotating shaft to the top of the bearing and thence will overflow back into the reservoir. The generator has a Kingsbury type thrust bearing below the rotor with the guide bearing combined on the thrust bearing collar which is forged integral with the shaft. These bearings are in a common oil pot with water circulation coils for cooling. Indicating thermometers with alarm attachments are embedded in each bearing.

The turbines will be equipped with the latest Woodward twin cabinet actuator type governors, each unit having a capacity of 259,000 foot-pounds at 300 pounds pressure. The actuators and pumping units are mounted on a fabricated steel sump base as an integral part and the whole assembly enclosed in a cabinet with all gauges and controls mounted on the front panel. The actuator and oil pressure systems of each pair of units are so interconnected that either pump or either pressure tank may be used to supply the oil requirements of either or both units or they may be operated separately. Each governor oil pump has a capacity of 200 gallons per minute at 300 lbs. pressure and is driven by a 50 H.P. motor. The governor fly balls are motor driven by the ball head motor which receives its power supply from the permanent magnet generator mounted on top of and directly connected to the main generator. The speed indicator, or tachometer, will be mounted on the actuator cabinet, and is actuated by the permanent magnet generator through a rectifier-resistor filter pack.

Electrical Equipment and Layout

The turbines will drive four umbrella type, vertical, air-cooled Westinghouse generators, each rated 39,000 KVA, 0.9 power factor, 3 phase, 60 cycles at 128.6 r.p.m. Each generator has its own direct connected exciter and pilot exciter.

A very complete system of ventilation is provided for cooling the generators and heating the power house. Outside air is drawn into the upper portion of the power house through adjustable louvers set in the downstream wall and one end wall of the power house. The air is then drawn into the individual machines, each generator requiring 80,000 cubic feet of air per minute. A total of fifty-four washable filters are mounted on top of each generator to filter the air before it enters the generator. The fans for drawing the air into the building and circulating it through the generator and exhaust air ducts are mounted on the generator rotor. After the air passes through the rotor and the stator coils it is discharged through the sides of the stator frame into a discharge air duct and thence outside of the building through another set of adjustable louvers located in the upstream wall of the power house. This eliminates any chance of short-circuiting the air circulation. Auxiliary dampers in the discharge air duct and in the generator room floor allow warm air to be discharged within the power house for heating and then re-circulated through the machines.

This system of air cooling the generators represents a departure from prevalent methods, since a great majority of modern units are of the water-cooled type. We were unable, however, to achieve any economy by using the water-cooled type. The air-cooled machines have the additional advantage of providing building heat during cold weather.

The generator room floor is served by two 75-ton traveling electric cranes, each with 15-ton auxiliary hooks. The cranes can be coupled together and by means of a lifting beam can be used to handle the generator rotor which is the heaviest piece of equipment. Each generator will be connected in a unit system with its own step-up transformer bank consisting of three General Electric single phase, water-cooled units, each rated 13,000 KVA connected 13,400 volts delta and 230,000 volts wye. Water for cooling the transformers will be supplied from the tailrace by two 1750 r.p.m. motor-driven pumps of 450 gallons per minute capacity, each under a 75-foot head.

Low voltage and 230 KV steel switching structures, including the main transformers, are located outdoors, upstream, close to the power house structure. Power supply from Littleton will be transmitted into the 230 KV system at Comerford Station by means of two single circuit 230 KV wood pole lines. Generation at Littleton will also furnish power supply into the 34.5 KV system in the Littleton area. Each of the 230 KV lines will be 6.7 miles long and will be equipped with expanded aluminum conductors having a cross section of about 0.4 square inches and an outside diameter in excess of one inch.

The first few hundred feet of the 230 KV line outlets of Littleton present a special problem because they cross over the spillway channel. It is recognized that turbulence of the water during spillway discharge in cold weather might cause excessive ice formation on any overhanging wires. We are therefore installing an insulated heating element in the conductor that by suitable switching can be made to carry all the current for such length of time as is necessary to melt or prevent ice formation.

Station service power will be obtained from two 500 KVA, 13800/480 V transformers, each connected to a main generator circuit through 15 KV fuses. Station service transformers will feed a control center in the power house to serve various 440 V station auxiliaries. A second 440 V control center will be located at the dam, fed from the power house control center to serve various motor-driven gates and hoists at the dam.

Foundation Treatment

Because of the seamy character of the ledge in some areas, a great deal of attention has been given to the treatment of the foundation of the dam. A grout curtain has been established beneath the upstream portions of all the concrete dam structures and beneath the cut-off trench of the earth dam for the distance in which it was carried to ledge. Grout holes were drilled from the toe blocks and galleries of the various structures to varying depths up to 100 feet below the surface, and grout pressures up to 130 pounds per square inch were used. Primary grout holes were spaced on twenty-foot centers with secondary holes on ten-foot centers and tertiary holes on five-foot centers.

In addition, in some areas, consolidation grouting was done by drilling patterns of holes and washing between them after which the entire group of holes was grouted.

Relief holes were also drilled extending from box drains in the base of the concrete sections.

Over 35,000 linear feet of grout holes have been drilled and over 6000 bags of cement used in the grouting operations. An additional 5000 feet of relief holes have also been drilled.

Concrete

A source of concrete aggregates was found a short distance from the site on the New Hampshire side. This consisted of an esker composed of sand and gravel which was washed, crushed and graded in an aggregate processing plant. The maximum size of stone used was six inches.

Concrete was mixed in an automatic batch type mixing plant containing six bins for storing aggregates. On a lower floor a pair of two-yard tilting type mixers batched the concrete. Adjacent to the mixing plant are 3 cement silos with screw feed and bucket elevator.

A fleet of six trucks, carrying four-yard buckets transported the batched concrete to the point of placement. Here one of two five-yard Manitowoc Speedcranes with 140-foot booms lifted the bucket and transported it to the forms. These were the first such machines to see service in New England. A stiff leg derrick has also been used to transport the concrete buckets in some areas.

Cement was Type II Portland cement and was supplied by several companies to assure a continuity of supply. It was shipped in bulk by rail and stored at a siding which was built in the Town of Littleton. The cement was inspected and tested at the manufacturers' plants prior to shipment.

The proportions for concrete were fixed by Thompson & Lichtner Co. in collaboration with a field laboratory which was completely equipped with testing apparatus and storage room. The specifications call for grades of concrete based on strength at 28 days varying from 2500 p.s.i. for the mass structures to 3500 p.s.i. for thin sections, floors, etc. An air entraining agent was added at the mixers.

Almost a quarter of a million cubic yards of concrete have been placed and on the bigger pours the rate of placement ran to 110 yards an hour and 1800 yards in a single 24-hour period.

Closure

The first steps toward the final closure of the dam began with the advent of low river flows in July of 1955. The concrete piers which had been formed in the diversion channel were raised to elevation 700 and a 10′ x 10′ sluice was formed in one pier at elevation 671, with a 10′ x 10′ Broome Gate installed at the upper end. Concrete was then placed in the three gaps between piers and sidewalls by successively stop logging one opening after another and pouring lifts of different height in such a manner that the water could always be passed through two openings while the third was closed off by the stop logs. This was necessary because the requirements of downstream water users made it necessary to pass some river flow almost continuously.

In order to guard against erosion of the ledge in the diversion channel near the base of the retaining wall by the water discharging from the sluice, we attempted to dissipate much of its energy within the structure. This was done by introducing several sharp 90-degree turns in the sluice passageway. Water entering the sluice opening in the pier was turned at right angles toward a vertical shaft, thence downward and again at right angles to a 10′ x 15′ opening which was left at the base of the structure between the two piers. A model made at the Alden Laboratory indicated that this scheme did reduce the exit velocity of the water.

A second sluice was installed at elevation 720 but since river flow has remained very low since closure began, the water had not approached the sill of the upper sluice when we finally reached the stage where we were able to use the penstocks for passing water. The upper sluice was therefore filled with concrete.

When the pond elevation rises to where we can pass down-river requirements through the penstocks, the broome gate will be closed and a concrete plug poured behind it. River flow will then be controlled by the intake gates until the pond reaches the sill of the tainter gates, after which it can be controlled by the tainter gates while work on the units is completed.

Basin Work

The dam will create a pond approximately 11 miles long and will impound 115,000 acre feet of usable storage with a maximum draw-down of 40 feet. The area of the pond will be about 3500 acres when full or about three-fourths the size of Newfound Lake in New Hampshire.

The creation of the pond has necessitated considerable work in the basin area. A main trunk line of the New England Tel. & Tel. Co. crossed the valley immediately above the dam site and this has been relocated. The main State Highway from Littleton, New Hampshire, to St. Johnsbury, Vermont, also crossed the area to be covered by the pond and about 5 miles of this highway has been relocated. Several town and county roads have also been relocated.

Three cemeteries which would have been inundated by the pond also were relocated and a total of 2400 acres have been cleared of trees and brush in preparation for filling the pond. We expect also to provide recreational areas along the shore, as we have done at other system properties, to accommodate fishing, boating and picnicking.

Organization

The work is being carried out for the New England Power Company, a subsidiary of the New England Electric System. All design, engineering and supervision for the development is being performed by the New England Power Service Company, the service organization for the New England Electric System, except the plans for the power house superstructure and access bridge which were made by Chas. T. Main, Inc., who have also been retained as Consulting Engineers. Ebasco Services, Inc. of New York has been retained as Construction Managers.

The Thompson & Lichtner Company is serving as concrete consultants and Professor D. W. Taylor of M.I.T. as soils consultant. Geological investigations are under the direction of Irving B. Crosby, Consulting Geologist, and model testing at the Alden Hydraulic Laboratory was under the supervision of Professor L. J. Hooper of Worcester Polytechnic Institute. Pittsburgh Testing Laboratories covered the inspection and complete radiographing of all penstock welding.

Contracts for the excavation of the Project and for the construction of the earth embankments have been awarded to B. Perini & Sons of Framingham, Massachusetts.

Contracts for concrete masonry construction and installation of mechanical equipment have been awarded to Morrison-Knudsen Company, Inc. of New York.

All electrical equipment will be installed by the New England Power Service Company.

Many other contractors are being employed on various parts of the work including H. B. Cummings of Woodsville, New Hampshire, on superstructure erection, Kenneth E. Curran, Inc. of Littleton, New Hampshire, on job buildings and many miscellaneous sub-contracts, Walsh-Holyoke Division of Continental Copper & Steel Industries, Inc. of Holyoke, Mass., on penstock fabrication and erection and Joy Manufacturing Company of Michigan City, Indiana, for diamond drilling.

An observation stand was built upstream of the site for the convenience of the public and over 200,000 persons have viewed the construction from this vantage point. A permanent visitors' house and promenade will also be built immediately downstream of the dam.

The development will share with our Comerford Plant the distinction of being the largest hydro-electric station in New England and, situated as it is in a beautiful natural setting of green hills and rolling meadows, can take its place proudly among the many scenic attractions of Northern New England.