ARROWROCK DAM

BOISE PROJECT, IDAHO

By Carl J. Hoffman

Shortly after the Reclamation Act was passed in 1902, the Boise project in southwestern Idaho was established to supply irrigation water to project lands and to supplement the supply to irrigated lands then being served through Warren Act contracts. The Arrowrock Reservoir was completed in 1916 as a part of the storage system for the project, impounding surplus winter and flood flow of the Boise River for use on the portion of the project lands situated between the Boise and Payette Rivers. Together with other reservoirs in the Boise and Payette River basins, Arrowrock Reservoir is now a part of a coordinated and integrated multiple-purpose storage system providing irrigation storage, flood control regulation, and power storage regulation for the project and surrounding developments.

Arrowrock Dam is located on the Boise River, about 4 miles below the junction of the north and south forks and about 22 miles upstream from Boise, Idaho. The river above the dam drains about 2,200 square miles on the western slope of the Sawtooth Mountain Range. The average annual flow of the river at the dam is 1,600,000 acre-feet, which, before upstream reservoirs were built, varied from high flood rates in the spring to a few hundred cubic feet per second late in the summer.

The original storage capacity of the reservoir was about 276,500 acre-feet with the water surface at the top of the spillway drum gates, when raised. In 1936, the dam and spillway crest were raised 5 feet, adding about 15,000 acre-feet of storage. Considering the deposition of silt within the reservoir storage space, the estimated usable storage capacity is about 284,000 acre-feet with the water surface at the top of the gates.

The reservoir is about 17 miles long, and covers an area at maximum storage level of about 3,000 acres. In shape it resembles the letter Y, as water backs up both the north and south forks of the Boise River.

DAM SITE

In 1903 and 1904, reconnaissance surveys were made at several reservoir sites on the upper waters of the Boise River, including rough surveys of several possible dam sites. Comparative cost estimates of dams at various sites were made, and in 1910 a drilling crew was sent out to explore the foundations at the more promising sites. Through a process of elimination, the Arrowrock site was chosen as most favorable, and testing of the foundation was continued in more detail during the latter part of 1910 and the early part of 1911.

Fifty-nine diamond-drill holes were sunk over the foundation area and along the spillway site, supplemented by numerous test pits, shafts, and tunnels above water line. The foundation rock was found to be a good quality hard granite, whose surface was nearly 90 feet below river level at the deepest place and at a depth of 65 to 70 feet over most of the remaining river area. The river-bed material was mostly sand, gravel, and boulders which were suitable for concrete aggregate.

The canyon at the dam site is fairly narrow, with high, steep, bare granite cliffs on the north side and less precipitous granite slopes on the south side, covered along the lower part for some distance by a cap of lava. The face of the lava cap rises almost vertically to a height of about 50 feet from its contact with the granite, which starts about 20 feet above the river water surface. The top of the lava bench is nearly level and, like the granite, is covered with a thin layer of overburden.

THE DAM

In 1916, when Arrowrock Dam was completed, it was the highest dam in the world. The dam is a curved gravity type, built of sand-cement concrete. The dam as originally built rose about 260 feet above river level, and was about 349 feet high from the deepest point in

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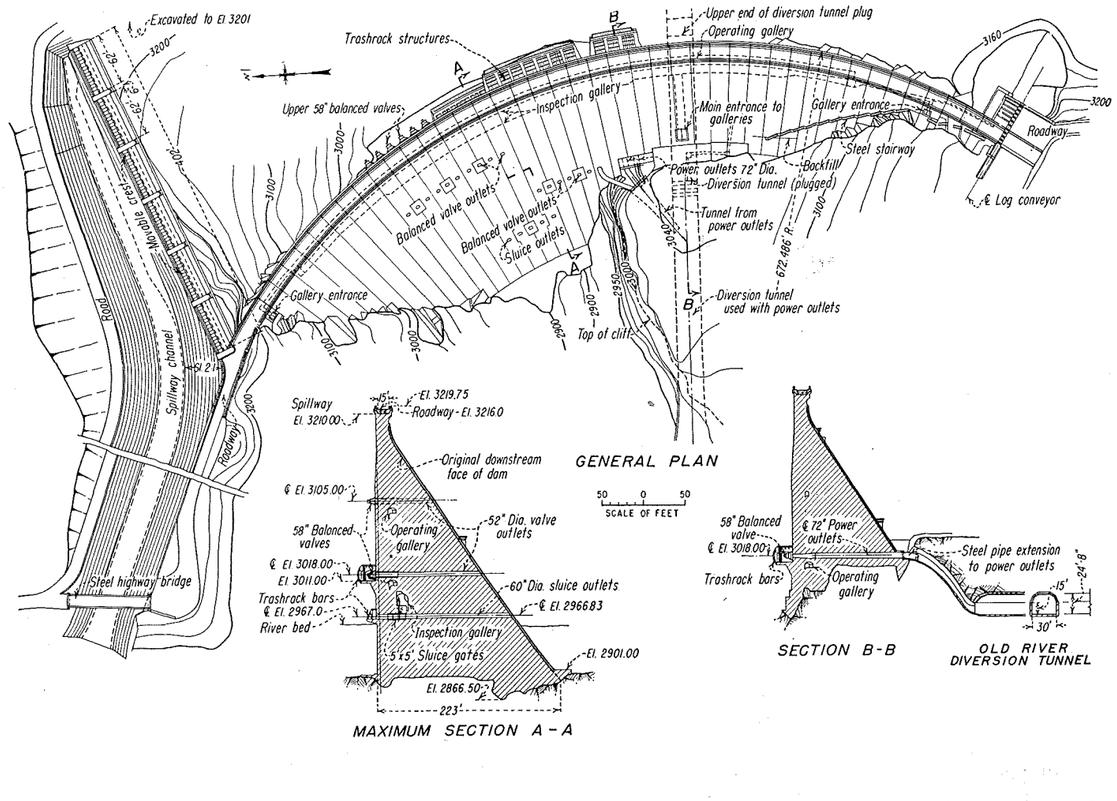
With Arrowrock Reservoir at a low stage, irrigation water for the Boise project pours from the upper tier of outlets.

the foundation to the top of the parapet. It was 223 feet thick at the base, 15.5 feet thick at the thinnest point near the top, and carried a 16-foot roadway along its top length of 1,100 feet. In 1936 the dam was raised by adding a 5-foot concrete capping along the crest, placing the crown of the road at the normal high storage level.

An inspection gallery and two operating galleries are situated inside the dam. The inspection gallery is located 25 feet from the upstream face of the dam. The lower, central portion is level and the abutment portions follow the profile of the foundation. The gallery has entrances at each end of the dam near the crest, and an additional entrance at the level of the lava bench on the left side. Two 24-inch square drains lead from the inspection gallery to the downstream face of the dam to discharge drainage water which collects in the gallery. Connecting with the inspection gallery are two horizontal operating galleries, each placed under a set of the regulating outlets which pass through the dam. The balanced valves controlling the flow through the outlets are operated from these galleries. The galleries, located 16 feet from the upstream face of the dam, are 87 feet apart in vertical distance and are connected by a spiral stairway. The lower gallery runs under the lower set of regulating outlets only, while the upper gallery extends along the entire length of the dam, providing access for inspection of the upper portion of the dam.

The foundation of the dam was pressure-grouted through two lines of holes drilled along the entire length of the dam at distances of 5 and 13 feet, respectively, from the upstream face. The holes were drilled at 10-foot centers to an average depth of 26 feet into the bedrock. For draining the foundation downstream from the grouted curtain, drainage holes, 27.5 feet from the upstream face of the dam, were drilled on 10-foot centers 26 feet into the bedrock. These holes emerge in the inspection gallery. For draining any seepage penetrating the concrete from the upstream face of the dam, vertical drainage conduits are spaced at 15-foot centers at a distance of 12 feet from the upstream face of the dam, extending from the inspection gallery to within 10 feet of the top of the dam.

Radial contraction joints were formed in the upper portion of the dam by building alternate sections at different times. The joints are spaced at various intervals dependent on the elevation and thickness of the



dam. Three vertical wells were formed in each joint which were later filled with concrete during cold weather, after concrete in the dam had undergone some contraction. A Z-strip, annealed-copper water stop was installed in each joint 5 feet from the upstream face of the dam, and immediately downstream from this strip a triangular drain was formed in the joint. These drains, provided to collect any water which percolates past the water stop, terminate in the inspection or operating galleries.

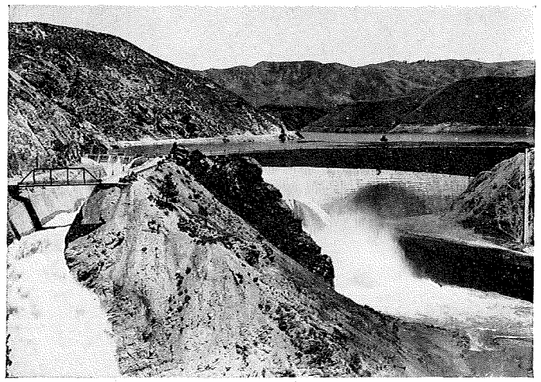
The principal quantities involved in the original construction of the dam were: 322,390 cubic yards of excavation, 585,165 cubic yards of concrete, 603,020 pounds of reinforcement steel, 10,490 linear feet of grout holes in bedrock, 24,540 linear feet of drainage conduits in concrete, 1,067 linear feet of drains, and 2,182 linear feet of operating galleries.

SPILLWAY

The spillway, a gated side-channel type, is located in a granite cut at the north or right end of the dam. The spillway weir is adjacent to the dam and extends along the north bank of the reservoir a distance of 402 feet. The spillway channel is approximately parallel to the weir, so that flow below the crest is turned at right angles and carried around the end of the dam to a point where the water discharges into Deer Creek, which flows into the Boise River about 800 feet below the dam. The spillway is designed for a capacity of 40,000 cubic feet per second with a head of 10 feet over the fixed crest of the spillway.

Flow through the spillway is controlled by six structural steel drum gates, each 62 feet long and 6 feet high. These gates, housed in recesses in the crest, are separated by 6-foot piers which contain the gate control mechanisms. The fixed crest of the spillway, when the gates are lowered, is at elevation 3210. The normal high storage level at elevation 3216 is maintained by raising or lowering the gates as necessary, either automatically or by manual manipulation of valves.

The channel cross section adjacent to the spillway weir increases in width and depth along its length and, at the lower end, has a 30-foot bottom width and a 50-foot depth. Beyond the end of the overflow weir, the channel continues for about 400 feet and terminates high on the cliff above the Deer Creek ravine. The channel is lined with reinforced concrete, anchored to



Arrowrock spillway discharges beneath the bridge on the left, and the outlet works discharge into the river channel in the center. The chute at the right is the logway, by which saw timber is passed over the dam.

the rock, and thoroughly drained with vitrified tile and weep holes.

The roadway across the dam passes along the spillway channel to the lower end, where a 96-foot-long steel highway bridge, 16 feet wide, crosses the channel.

The principal quantities contained in the spillway as originally built were: 359,000 cubic yards of excavation; 1,300 cubic yards of backfill; 25,564 cubic yards of concrete; 708,690 pounds of reinforcement steel; 641,770 pounds of gates, machinery, and structural steel; 5,030 linear feet of drains; and 50,200 pounds of structural steel in the highway bridge.

OUTLET WORKS

There are 25 outlet conduits through the dam, in three tiers, arranged so that when the conduits are discharging, the water falls into the river bed. The lower tier of five sluicing outlets is located at the elevation of the river bed, 249 feet below the crest of the dam. These outlets are 60 inches in diameter. They are protected by a trashrack and are controlled by 60- by 60-inch slide gates, operated by oil pressure.

Ten outlet conduits are located 198 feet below the crest of the dam. Three of these are 72 inches in diameter and are reinforced so they may become penstocks in connection with a possible future power development. The remaining seven conduits are 52 inches in diameter. All 10 conduits in this middle tier are controlled by 58-inch balanced valves placed at the conduit entrances and protected by trashracks.

The top tier of 10 outlet conduits is located 111 feet below the crest of the dam. These are similar to the 52-inch diameter conduits in the middle tier, except that the trashracks are omitted.

The sluice gates are not intended to be operated at heads greater than 75 feet, but they are so designed that they can be opened under a head of 125 feet in an emergency. The discharge at the 75-foot head is about 5,000 cubic feet per second, and at the 125-foot head about 6,700 cubic feet per second. The regulating outlets are designed to operate under a maximum head of 100 feet, at which head they will discharge 1,000 cubic feet per second each. The total length of all outlet conduits is 2,821 linear feet, and they involved the placing of 2,672,300 pounds of gates, machinery, and structural steel.

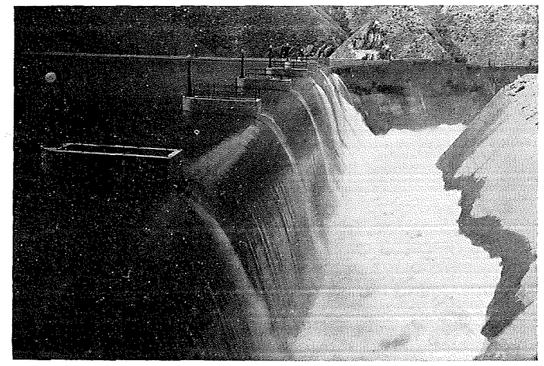
PRELIMINARY CONSTRUCTION WORK

Before beginning actual construction on the dam, it was necessary to perform considerable work of a preparatory nature, including the construction of a telephone system, access railroad, wagon road, power plant, transmission line, sawmill, construction camp, and diversion works for carrying the river past the dam site during early construction. All work was performed by Government forces with the exception of the grading of the railroad.

The entire construction plant at Arrowrock, with the exception of a steam shovel, dragline excavator, and dinkey engines, was operated by electricity. To furnish the necessary power, a 1,500-kilowatt power plant was constructed at the Boise Diversion Dam, 14 miles below Arrowrock. A duplicate transmission line was built from the power plant to Arrowrock, and a single line to Barberton, 3 miles from the plant, where it connected with the line owned by the local power company.

The diversion works consisted of an upper and lower cofferdam and a tunnel constructed through the granite below the lava bench at the south abutment of the dam.

Smooth flow over the spillway crest at Arrowrock breaks into turbulence in the outflow channel.



The tunnel was designed for a flow of 20,000 cubic feet per second and the cofferdams were designed to withstand overtopping in case of a larger flood.

The diversion tunnel was 470 feet long and in cross section was 30 feet wide and 25 feet high, with an arched roof. The bottom and sides of the tunnel were lined with concrete, and the roof was supported by timbers. The entrance and exit of the tunnel were both bell shaped to avoid loss of head and to increase the discharge. The upper cofferdam was about 200 feet long and 40 feet high, and was built of timber cribs filled with rock, gravel, and fine material sluiced into the crevices. The faces of the cribs were of solid timber construction, with the joints calked with oakum. A sheet piling cut-off was provided. The lower cofferdam was 150 feet long and 25 feet high with construction similar to that for the upstream cofferdam. Centrifugal pumps, mounted on cars which could be raised or lowered on an inclined track, served to pump out seepage water from the excavation.

When there was no longer any need for the diversion tunnel, it was plugged with concrete for a length of 190 feet under the dam.

CONSTRUCTION

Dam construction in the river bed was performed in two stages. During the first stage, excavation and construction for an upstream portion of the dam were carried forward to an extent sufficient to protect the work during the flood season. This excavation and concrete work was successfully accomplished between the flood seasons of 1912 and 1913. The completed section of the dam then served as an effective cofferdam to prevent flood damage and seepage into the deeper workings during the remainder of the excavating and concreting.

The material in the river bed was largely gravel and sand, with perhaps 5 to 10 percent large boulders. Inasmuch as concrete materials were not plentiful in the vicinity of the work, all excavated material which was suitable for concrete aggregate was stored for such later use.

On the south abutment, the lava cap was entirely removed in order that the dam might be founded upon the underlying granite. This material, along with other materials not suitable for concrete, was deposited upstream and downstream from the dam site. The excavation for the abutments was carried on just ahead of concreting and was completed in November 1915.

Concrete work on the dam started in November 1912, and was completed in November 1915. The dam was actually built in three stages. The first stage, as indicated previously, served to protect the subsequent work. It consisted of the lower upstream portion of the dam to a height of about 40 feet above high water in the river, and was of ample thickness to withstand water pressure to that height. The second stage brought the full thickness of the dam to the top of the first section, and the third stage completed the dam.

The best progress was made during the months of April, May, June, and July 1914, when more than 200,000 cubic yards of concrete were placed, an average of more than 50,000 cubic yards per month. In June 1914, 56,500 cubic yards were placed in 26 working days, an average of 2,170 cubic yards per day of two 8-hour shifts.

The concrete aggregate for the first and second stages of the dam, 186,000 cubic yards, was obtained from the river-bed excavation. The remainder was hauled over the railroad from a gravel pit located near the Boise Diversion Dam, 14 miles below Arrowrock.

The sand-cement for the concrete was composed of standard portland cement to which was added a little less than an equal amount of pulverized granite, reground to such a fineness that 90 percent would pass a No. 200 sieve. Besides the rigid fineness test, the sand-cement was required to pass all the standard physical tests for portland cement. The concrete made of this sand-cement was slower in setting and hardening than that made with straight portland cement. The sand-cement plant was located at the north abutment of the dam and had a capacity of 2,000 barrels of sand-cement in a 24-hour period. The plant manufactured a total of 586,450 barrels of sand-cement at an estimated saving of approximately $300,000.

Two 12-ton cableways, each 1,500 feet long with 60-foot stationary head towers, were installed so as to command the entire area of the dam. These cableways were assisted by four 10-ton stationary derricks, two 6-ton traveling derricks, and several small stiff-leg derricks. A steam-operated dragline excavator with a 2½-cubic-yard bucket was used for excavating part of the foundation of the dam. Also, a 70-ton steam shovel with a 2½-cubic-yard dipper was used for excavating and for loading gravel at the Boise Diversion Dam gravel pit.

The aggregate screening and crushing plant and the concrete mixing plant for constructing the first and second stages of the dam were located on the cliff on the south abutment, directly beneath the main cableways. The mixing plant was a two-unit installation, consisting of 1-cubic-yard mixers electrically operated. Concrete was delivered into movable hoppers and transported by the cableways to any point desired.

Upon completion of the second stage of the dam, the mixing plant was moved to the lava bench just below the dam and another mixing unit added. Aggregates for

the second plant were hauled by railroad from the gravel deposit near the Boise Diversion Dam. The concrete was discharged from the mixers into 2-cubic-yard trolley cars and carried to a central distributing tower 150 feet high. From this tower the concrete was distributed via cableways by buckets and hoppers in the same manner as that employed in the first stages of the dam.

For concrete placing in the upper portion of the dam, the cableways could no longer conveniently cover the work on the long sweeping area, and the distributing system was changed. A track and dump-car system was employed, the concrete being conveyed from the mixers by the main cableways to hoppers placed at both ends of the dam. From the hoppers, the concrete was carried to any point by dump cars running on the track. The track and hoppers were raised as the work progressed.

Concrete for the spillway was obtained from the second mixing plant, and was transported from the plant to a dumping hopper at the spillway site by one of the main cableways. The concrete was distributed from the hopper to the various parts of the work by chutes, dump cars, an auxiliary cableway, and a traveling derrick.

Since there are some 3 billion board-feet of timber growing on the Boise River watershed above Arrowrock Dam, it was considered desirable to provide a means for floating this timber past the dam. Therefore, a log conveyor system was built at the south end of the dam, designed to handle 60 million feet of logs during a season lasting from May 1 to July 15. The conveyor consists of a lift to raise the logs from the reservoir to a log deck by cable loops, "live" rolls across the dam, an endless chain chute 390 feet long, and a gravity chute 245 feet long. The structures are built of reinforced concrete and structural steel. All the original construction was performed by Government forces.

1936–37 ALTERATIONS

During the 20 years following the construction of the dam, the downstream face, the spillway channel lining, and other exposed surfaces which were made of the sand-cement concrete, suffered some disintegration. This was due, primarily, to the fact that the sand-cement concrete was very porous and absorbed water freely, resulting in rapid spalling with alternate freezing and thawing. It became apparent as early as 1927 that remedial measures would ultimately be necessary to protect the concrete surfaces from freezing and thawing action.

In 1935, funds were made available for making repairs to the dam and spillway and the contract for construction was awarded to T. E. Connelly, Incorporated, of San Francisco, Calif., in 1936.

The repairs to the dam included an 18-inch reinforced concrete slab on the downstream face below elevation 3197.75, and a gunite covering on the remaining portion of the face above that elevation. The spillway channel floor was covered with a reinforced concrete slab and the side lining covered with a layer of gunite, reinforced with steel mesh. Incident to the repairs, the dam and spillway crest were raised, as described previously.

To unwater the foundation and gain access to the downstream toe of the dam for the face repairs, a tunnel was constructed connecting two of the power outlets and one irrigation outlet in the lower tier of conduits with the original diversion tunnel below the concrete plug. A cofferdam was constructed upstream from the old diversion tunnel outlet, and water for irrigation demands was diverted through this tunnel during the repair period.

The cost of original construction was approximately $4,800,000 and the cost of repairs in the neighborhood of $600,000.

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