

CHAPTER VI. Design--OUTLET WORKS

47. GENERAL. River outlets having a capacity of 15,000 cubic feet per second with the reservoir at elevation 3490, which is the minimum water surface for power operation, were installed in the dam near the left abutment. The river outlets provide for releases for downstream commitments when the powerplant is not in operation and during the period of final closure of the diversion tunnels. The outlets will also be used to maximum capacity during maximum flood releases. The centerline of the intake is at elevation 3374 which is about 30 feet above the estimated 100-year silt level in the reservoir.

The outlet works consists of four 96-inch-diameter steel pipes with cast iron bellmouth intakes, hollow-jet valves for regulation, and ring-follower gates for emergency closure. A bulkhead gate, which operates under balanced head, is provided at the upstream face of the dam to provide access for servicing the ring-follower gates. A reinforced concrete trashrack structure with structural steel bars protects the entrance. The location of the outlet works is shown on figures 109 and 110.

To avoid excessive velocities in the outlet pipes, a criterion was established limiting the maximum discharge of each outlet pipe to 3,750 cubic feet per second except in cases of emergency. Discharge curves are shown on figure 111.

48. SELECTION OF LOCATION. The best arrangement for the outlets in the dam was found to be two parallel outlets in each of two 60-foot-wide blocks. The centerline distance between the outlets in the dam, 15 feet 7 inches, was dictated by the required clearance for the bulkhead gate frame metalwork around the bellmouth intake. The minimum distance between the centerlines of the outlets and the radial contraction joints in the dam was set at 1-1/2 outlet diameters. Radii of bends are 4 diameters except where lack of space required using a bend of 3 diameters.

The ring-follower gates are located in a chamber (fig. 112) in the dam 60 feet downstream from the face of the dam. To facilitate installation of the gates, blockouts were provided in the gate chamber floor. A vertical shaft from the chamber to the roadway at the top of the dam was provided for removing gate parts for servicing. Special expansion joints in vaults, to

allow for movement in three directions, were designed for the outlet pipes where they leave the dam. These joints accommodate the movements of the dam when the dam is fully loaded (fig. 113).

Since the powerplant structure occupies the entire bottom of the canyon from abutment to abutment, it was necessary to locate the outlets in the mass concrete beneath the service bay and machine shop as they leave the dam. In this area, they were set two above each other at minimum spacing. Beyond the machine shop the outlets were encased in concrete and located below the powerplant parking area. The hollow-jet regulating valves are located about 700 feet downstream from the axis of the dam. In this area, the outlet pipes are spread apart and are all brought to elevation 3175. The layout of the downstream end of the river outlets is shown on figure 114. The location of the valves and their operation were studied in a hydraulic model.¹

49. STRUCTURAL DESIGN. (a) *General.*—The design of the river outlets was based on concrete having a compressive strength of 3,000 pounds per square inch at 28 days for structural concrete and 2,500 pounds per square inch at 28 days for mass concrete.

The allowable working stresses are shown on figure 71, except that the allowable stress in the reinforcement around the pipes in the dam was increased to 25,000 pounds per square inch.

(b) *Trashrack Structures.*—The concrete trashrack structures (fig. 115) were designed for a differential waterload of 20 feet, temperature effects, and dead load.

(c) *Outlet Pipes.*—The reinforcement requirements around the outlets and in the surrounding mass concrete were as follows (fig. 110):

(1) Bellmouth casting at intake. It was assumed that the casting could take no tensile stress; therefore the opening was reinforced for the total tensile forces due to dam stresses, internal bursting pressure, and temperature effects.

(2) From the downstream end of the bellmouth intake to the upstream edge of the ring-follower gate blockout and from the

¹ "Hydraulic Model Studies of the Spillways and Outlet Works—Glen Canyon Dam." Hydraulic Laboratory Report No. 469, Bureau of Reclamation, February 18, 1964 (unpublished).

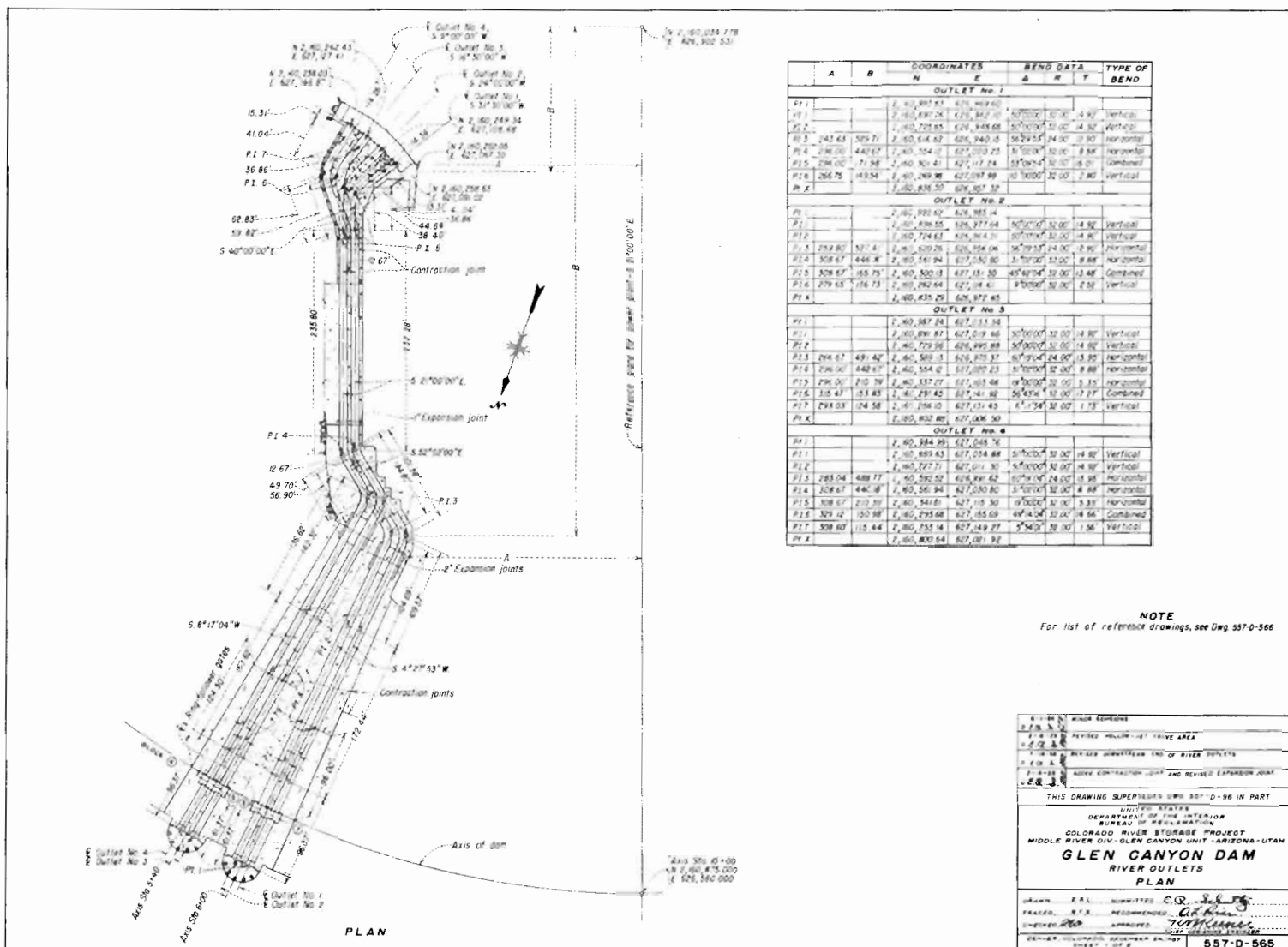


Figure 109.—Plan of river outlets.



Figure 111.—Discharge curves of river outlets.

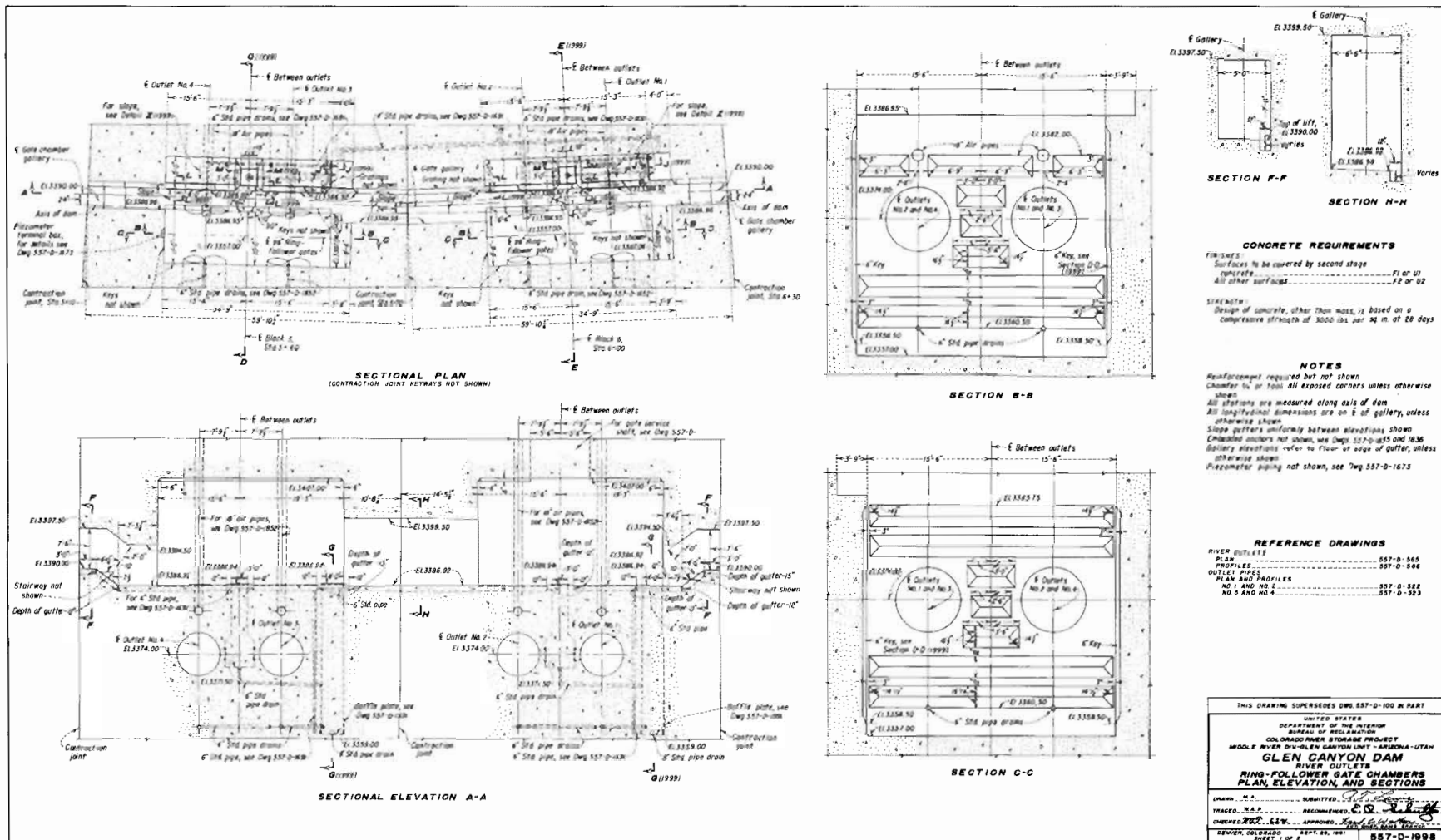
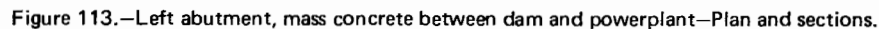


Figure 112.—River outlets, ring-follower gate chambers—Plan, elevation, and sections. (Sheet 1 of 2.)





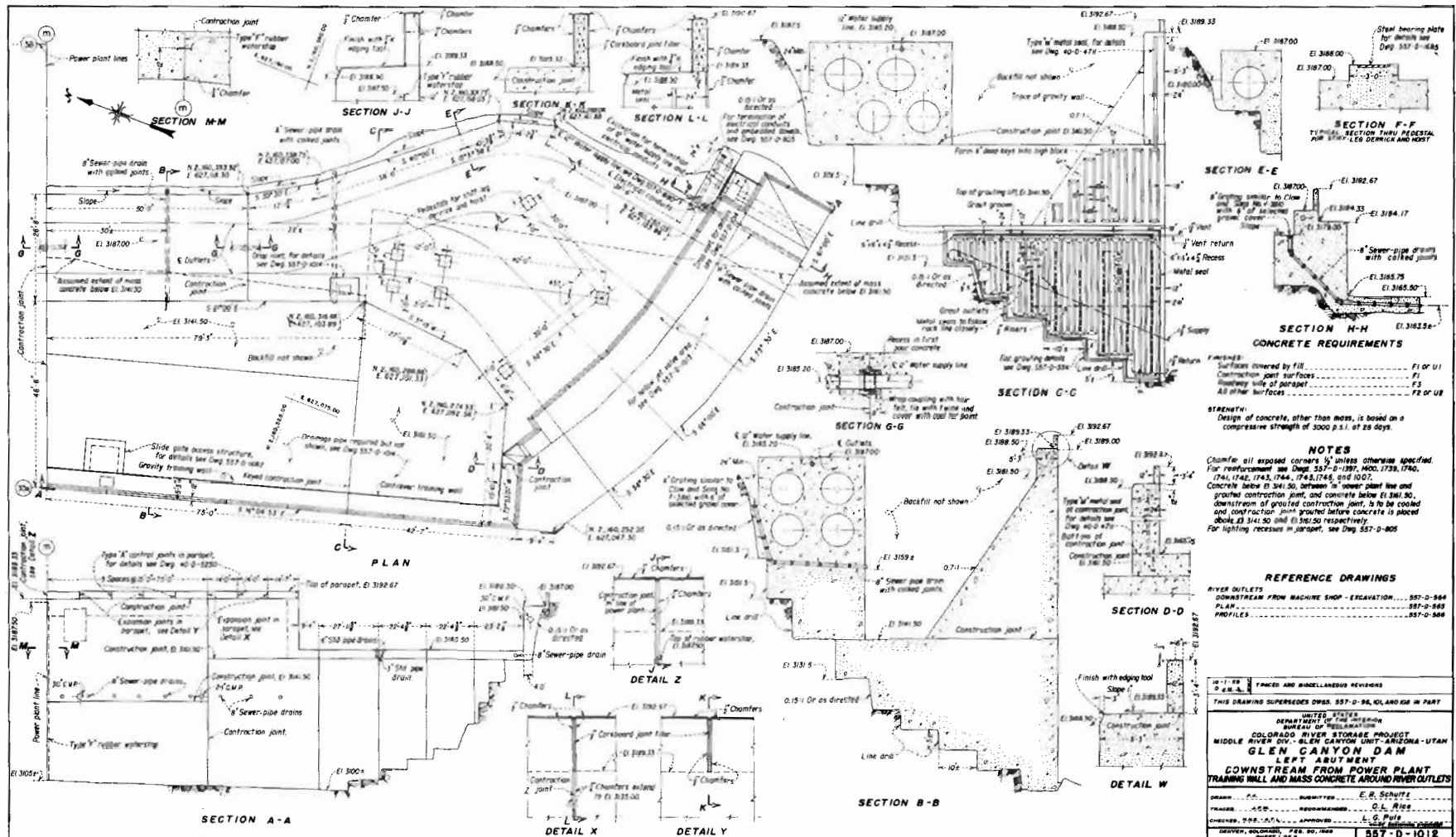


Figure 114.—Left abutment downstream from powerplant—Training wall and mass concrete around river outlets. (Sheet 1 of 2.)

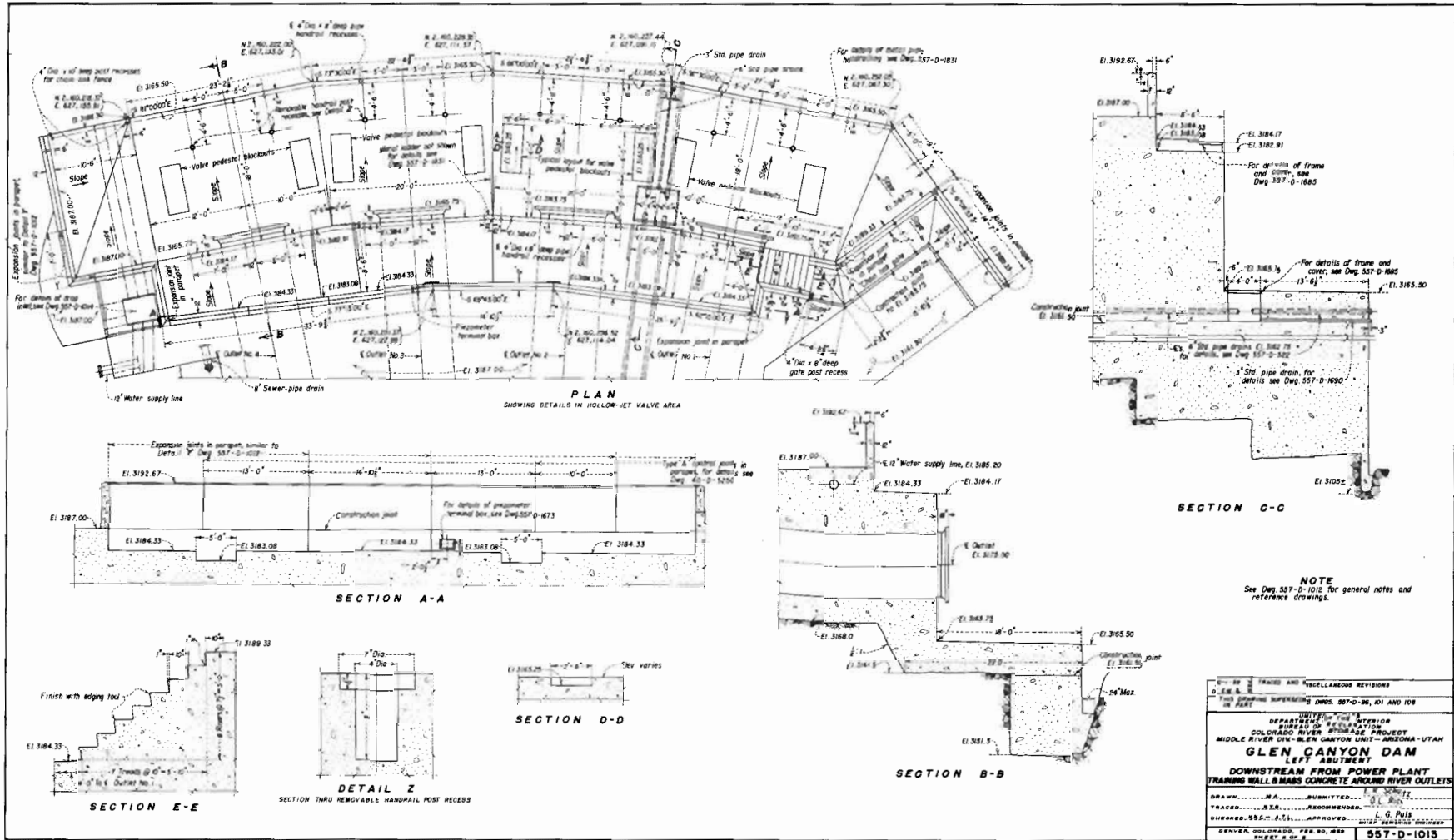


Figure 114.—Left abutment downstream from powerplant—Training wall and mass concrete around river outlets. (Sheet 2 of 2.)

Figure 115.—River outlets trashrack structure—Plans and sections.

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downstream edge of the ring-follower gate blockout to a point 40 feet upstream from the upstream edge of the expansion joint vault, the outlets were reinforced for tensile forces due to dam stresses and temperature effects.

(3) From a point 40 feet upstream from the upstream face of the expansion joint vault to the upstream face of the expansion joint vault, the outlets were reinforced for tensile stresses due to dam stresses, internal bursting pressures, and temperature effects. The outer face of the surrounding mass downstream from the downstream face of the dam was also reinforced to further control surface cracking.

(4) From the downstream face of the expansion joint vaults to the downstream end of the machine shop (m-line), the outlets were reinforced for tensile forces due to internal bursting pressure and for unbalanced forces in the pipe bends.

The outer face of the surrounding mass concrete was also reinforced in order to control surface cracking.

(5) From the downstream end of the machine shop to the hollow-jet valves, the outlets were reinforced for tensile forces due to internal bursting, truck and trailer loads, and unbalanced forces in the pipe bends. The outer face of the surrounding mass concrete was also reinforced in order to control surface cracking.

The second-stage concrete around the ring-follower gates was reinforced for tensile forces due to internal bursting pressure within the gate frames and bonnets.

50. 10.33- BY 10.33-FOOT BULKHEAD GATE. (a) *Description*.—The bulkhead gate is used for emergency closure of the four river outlets as shown on figure 116. When not in use, the gate is stored on the erection and storage platform at the top of the dam. The gate was manufactured by Johnson Machine Works, Chariton, Iowa, under invitation No. DS-5493. The frames were manufactured by Steward Machine Co., Birmingham, Ala., and the anchor bolts by Fulton Shipyard, Antioch, Calif., under invitation No. DS-5370.

(b) *Design*.—The design head is 343 feet with maximum water surface at elevation 3711.00. A lifting frame is connected to the gate for the raising and lowering operations. The gate and lifting frame slide in

the guides embedded in the upstream face of the dam. The lifting frame is attached to the gantry crane on the top of the dam. The maximum travel of the gate in the guides is approximately 355 feet.

The gate consists of a skinplate supported on horizontal wide-flange beams which are connected to vertical end beams along the sides of the gate. The hydraulic force on the skinplate is transmitted to the horizontal beams and the reactions are carried through the vertical end beams to the seats embedded in the upstream face of the dam. The gate is operated only under balanced pressure.

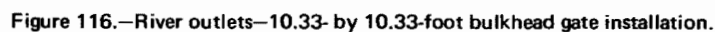
Double-stem rubber seals are mounted on the downstream side of the skinplate and contact the embedded seal seats when the gate is in the lowered position. The water pressure on the upstream side of the seals provides effective contact with the seats preventing leakage into the river outlet conduit. Lateral movement of the gate is controlled by means of guide shoes mounted at the four corners of the gate. The shoes engage the guides along the upstream face of the dam.

The estimated movable weight of the gate is 38,000 pounds. The estimated weight of the gate frames and anchorage for the four river outlets is 153,500 pounds.

The gate was designed for a head of 343 feet. The design was based on the following allowable unit stresses in pounds per square inch:

Combined longitudinal and transverse stresses in skinplate	20,000
Tension in extreme fibers of members subjected to bending	15,000
Compression in extreme fibers of members subjected to bending	14,000
Shear on gross area webs	9,500
Shear on rivets	11,500
Shear on ribbed bolts	15,000
Bearing on ribbed bolts and rivets	23,000

51. 96-INCH RING-FOLLOWER GATES AND CONTROLS. (a) *Description*.—Four ring-follower gates and two sets of controls are provided for normal closure of the river outlets when the hollow-jet valves are not in use and for emergency closure under full flow if the hollow-jet valves should become inoperable. Ring-follower gates were selected because of the absence of any obstruction in the fluidway of the high-velocity flow. The ring-follower gates (fig. 117) were manufactured by Goslin-Birmingham Manufacturing Co., Inc., under invitation No. DS-5269.



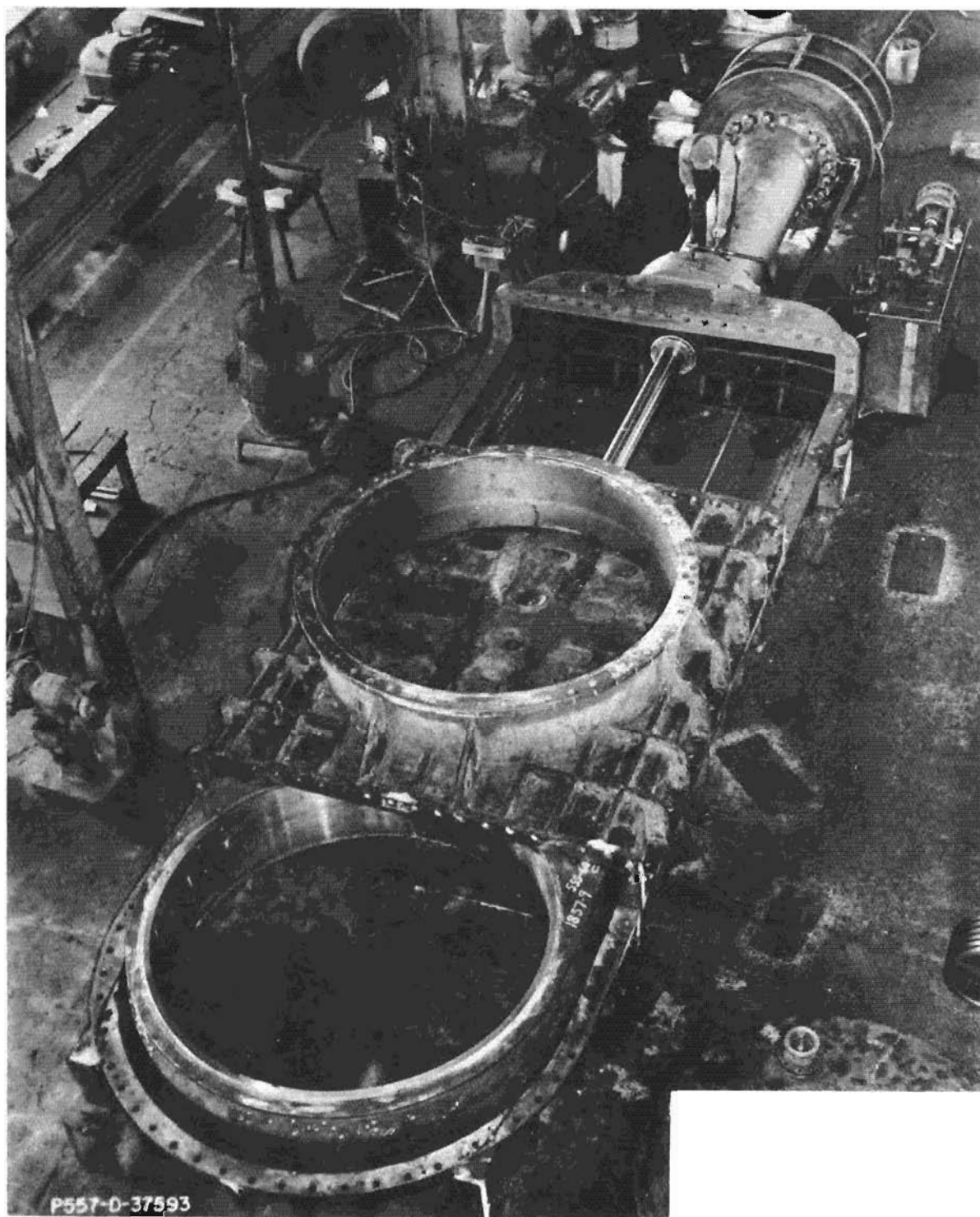


Figure 117.—96-inch ring-follower gate. The gate is shown in a horizontal position in the shop with the upper and lower upstream bonnets removed and is in the process of being tested.

The controls were manufactured by Kendo, Inc., under invitation No. DS-5498.

The ring-follower gates and controls are located upstream from the hollow-jet valves, near the axis of the dam, in the ring-follower gate chambers as shown on figure 118. A set of controls is located adjacent to each pair of ring-follower gates as shown on figure 119.

(1) *Ring-follower gate.*—The ring-follower gate is of cast and welded steel construction and consists basically of a body, a leaf, and a hydraulic hoist which is an integral part of the gate. The gate is of the slide type with a leaf made to include a follower ring having a circular opening equal to the diameter of the pipe to provide an unobstructed water passage when the leaf is in the open position as shown on figure 120. The hoist has a 27-inch-diameter cylinder and a travel of 8 feet 8 inches. A direct-reading position indicator is located adjacent to the hoist cylinder. The estimated weight of each ring-follower gate is 140,000 pounds.

(2) *Controls.*—Each control cabinet is of steel construction and encloses the control system for two ring-follower gates as shown on figure 121. A 110-gallon oil supply tank is located on top of each control cabinet to keep the minimum oil level above the gate cylinders. An oil-level gage is located on each tank. The estimated weight of one set of controls is 10,000 pounds.

(b) *Design.*—The ring-follower gate was designed to operate under a maximum reservoir head of 337 feet and a hoist oil pressure of 2,000 pounds per square inch. The hoist capacity was based on the weight of the leaf plus the sliding friction of the gate seals, using a friction coefficient of 0.6. Nickel-copper alloy seats were used on the gate body and bronze seats on the leaf to provide a low-friction and rust-resisting sliding surface. The maximum waterload on the gate leaf produces a bearing pressure between the sliding surfaces of the leaf and body seats of 715 pounds per square inch. The piston stem was made of nickel-copper alloy to prevent rusting. A hand-operated mechanical latching device was provided on the upper cylinder to hold the gate in the open position.

The equipment in each control cabinet consists of two oil pumps, each having a capacity of approximately 10-1/2 gallons per minute when pumping oil at 2,000 pounds per square inch; two 15-horsepower, 440-volt, 3-phase, 60-cycle electric motors; connecting piping, and hydraulic and electric controls. Remote controls were not provided.

(c) *Design Stresses.*—

(1) *Tension.*—The allowable design stresses in tension for the following materials were based on the yield point or the ultimate strength of the material. The smaller of the tabulated values was used in each instance.

Material	Type	Percent of yield point	Percent of ultimate tensile strength
Steel	Rolled or forged	40	25
Bolt steel	Rolled or forged	25	16.5
Cast steel	Castings	33	20
Brass or bronze	Rolled or cast	33	16.5

(2) *Compression.*—The allowable design stresses in compression used for the materials listed above were the same as for tension.

(3) *Shear.*—Allowable design stresses in shear were not more than 0.6 the allowable design stresses in tension.

(4) *Structural steel.*—Allowable design stresses for structural steel in tension or compression was not more than 20,000 pounds per square inch. In general, structural steel stresses were based on the American Institute of Steel Construction "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings," 1961.

(5) *Hoist cylinders.*—Allowable design stresses for hoist cylinders were based on the recommendations of the ASME Boiler and Pressure Vessel Code—Unfired Pressure Vessels—Section VIII.

52. STEEL OUTLET PIPES. (a) *Description.*—Four outlet pipes (figs. 122 and 123) are provided to pass water through the dam when the reservoir water surface is below penstock intakes, and to supplement turbine and/or spillway discharge when required for flood control. The outlet pipes were installed under specifications No. DC-4825. Fabrication was performed under invitation No. DS-5052.

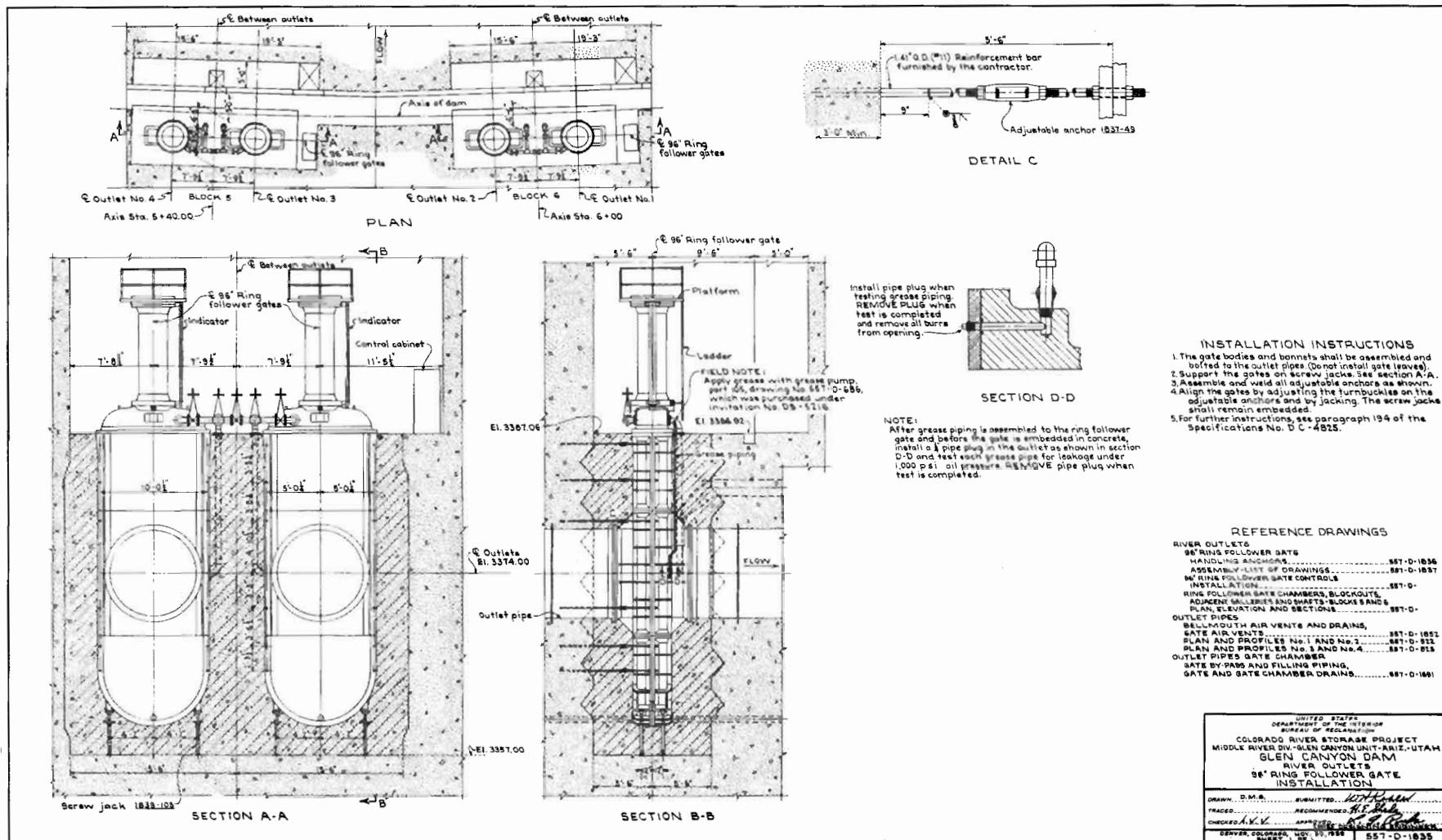


Figure 118.—River outlets, 96-inch ring-follower gate installation.

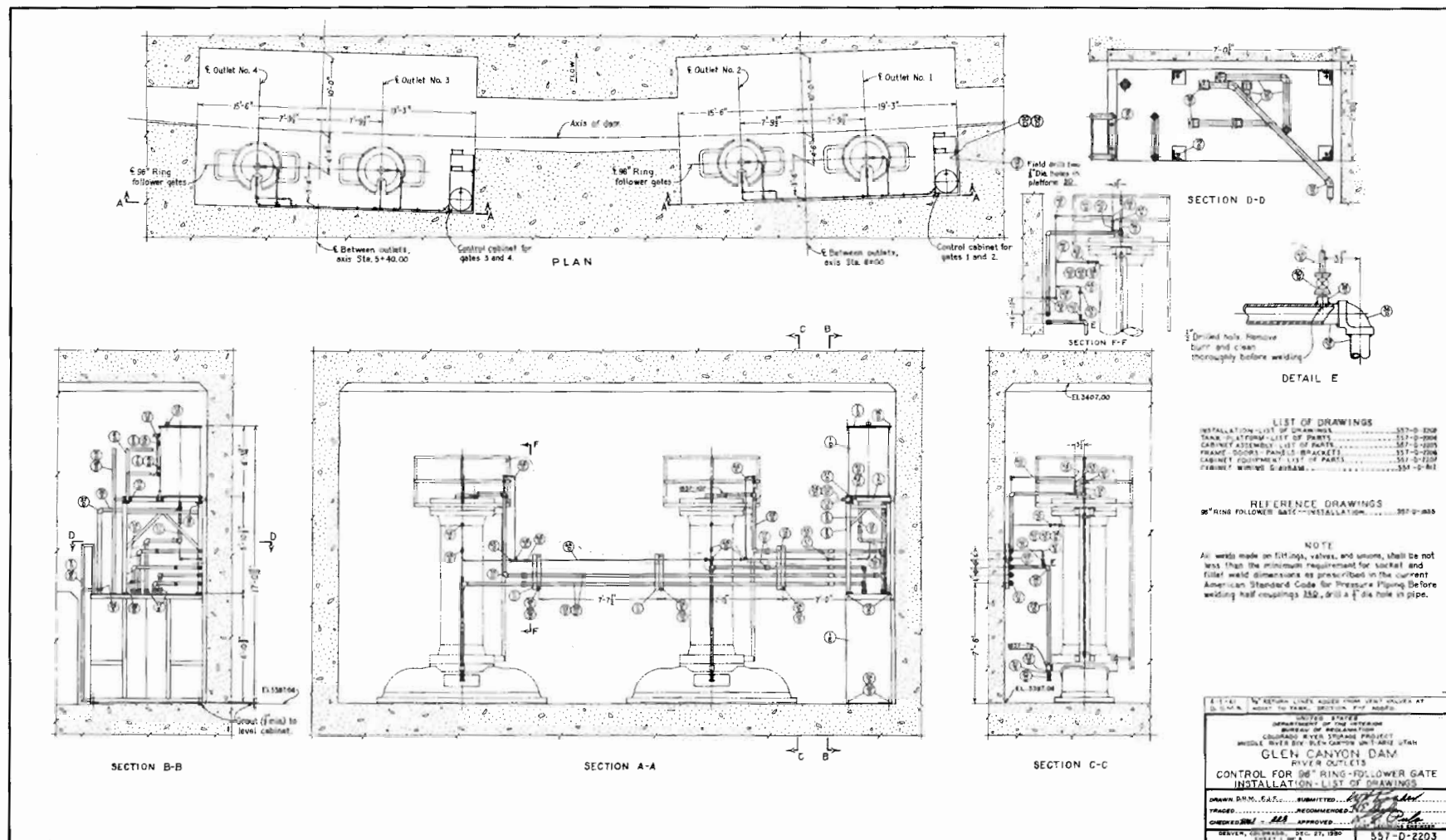


Figure 119.—River outlets, 96-inch ring-follower gate control—Installation.

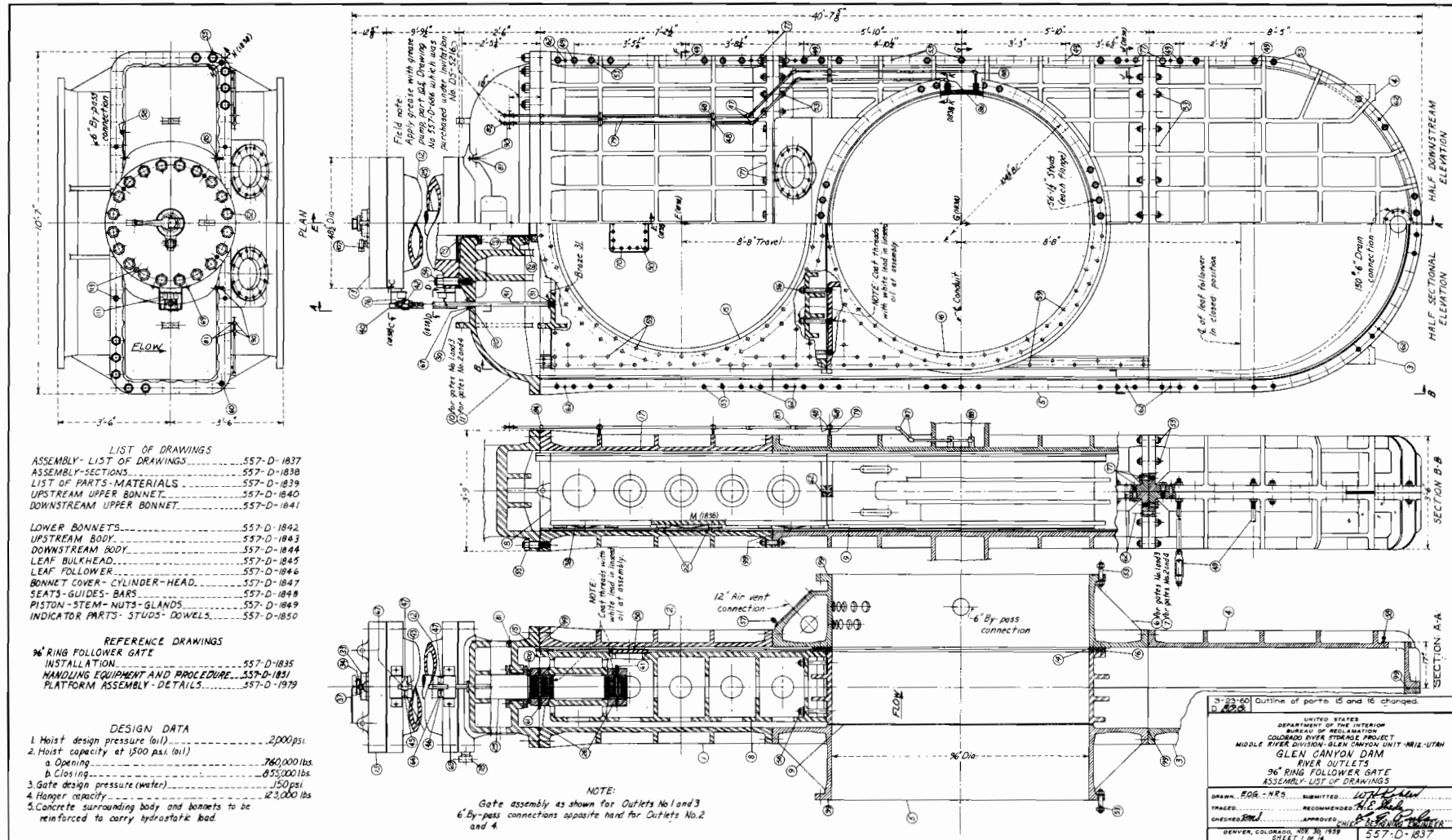


Figure 120.—River outlets, 96-inch ring-follower gate assembly.

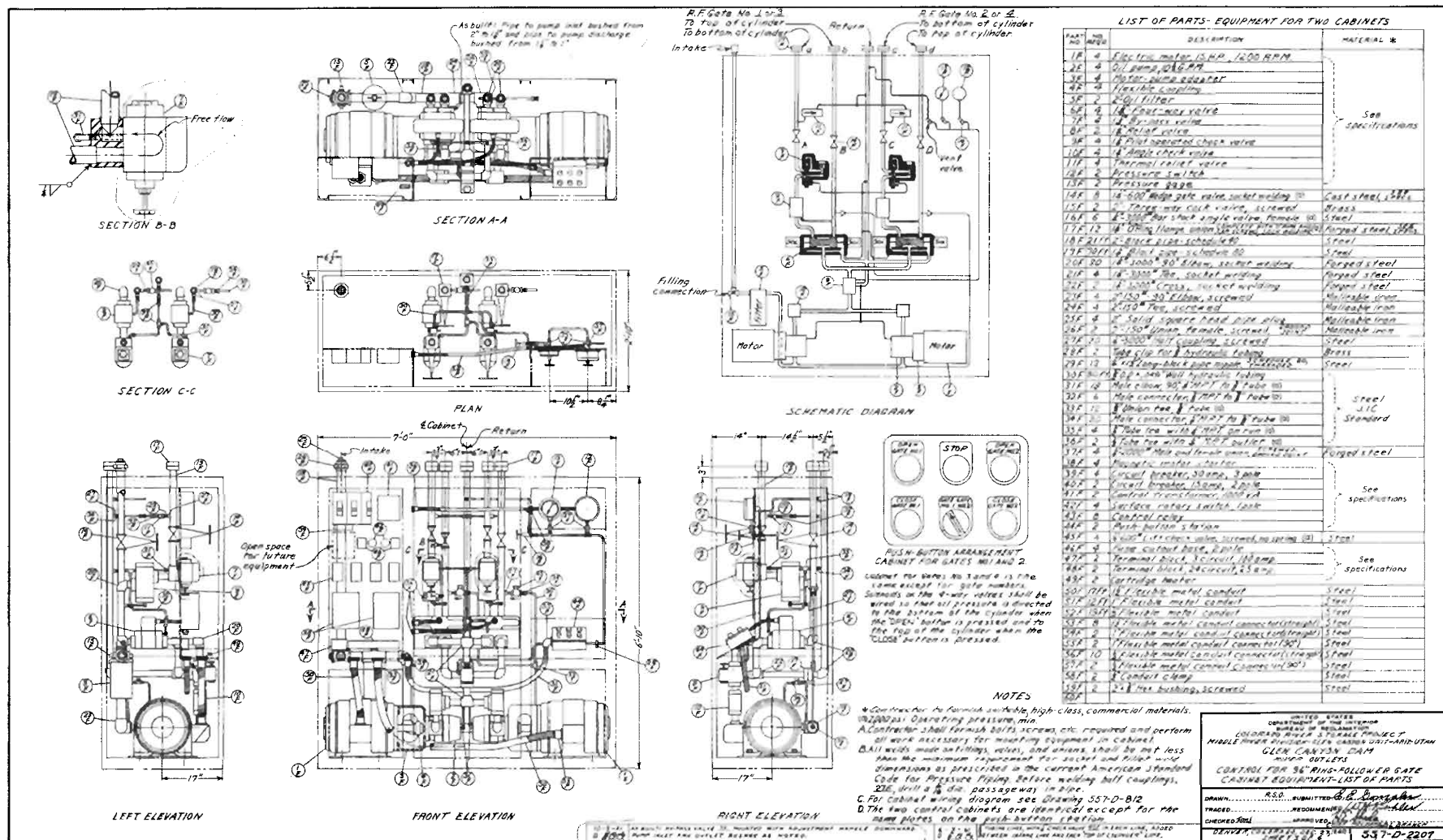


Figure 121.—River outlets, 96-inch ring-follower gate—Cabinet equipment.

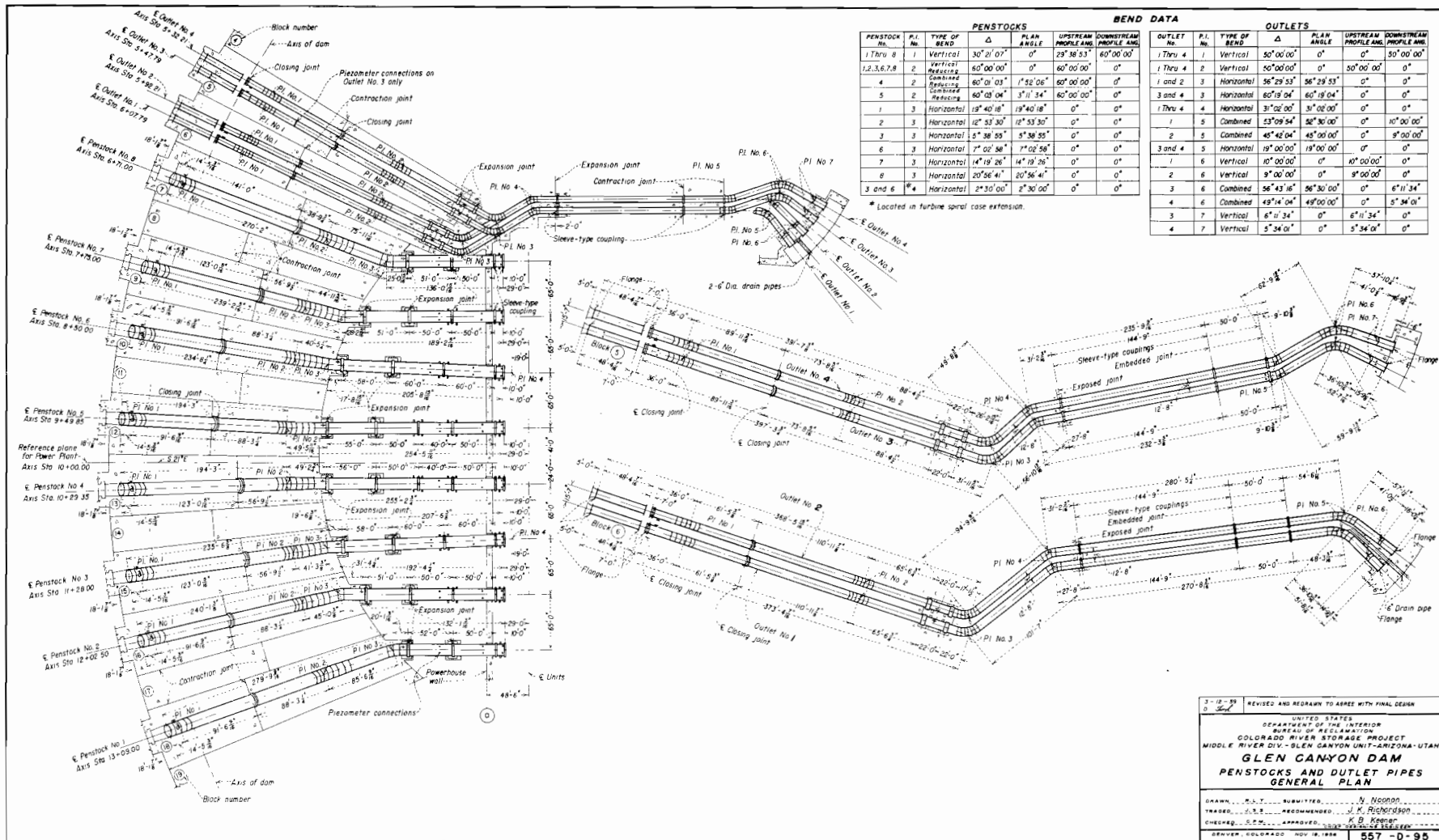


Figure 122.—Dam penstocks and outlet pipes—General plan.



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The outlet pipes have an inside diameter of 8 feet. They begin at the downstream ends of cast iron bellmouths in the upstream face of the dam at centerline elevation 3374.0 near the left abutment. Each pipe runs level for about 90 feet, then slopes downward and emerges from the dam and passes around the powerplant to the outlet structure. Outlet pipes No. 1 and 2 emerge from the dam at centerline elevation 3168.5, run level to the outlet structure and there lift to centerline elevation 3175.0. Pipes No. 3 and 4 emerge from the dam at centerline elevation 3179.0, run level to the outlet structure and there drop to centerline elevation 3175.0, in line with the other outlet pipes. A ring-follower gate is installed in the first level run of each pipe. The outlet pipes terminate at hollow-jet type discharge regulating valves. Each outlet pipe is approximately 930 feet long.

Minimum and maximum outlet pipe plate thicknesses are 9/16 and 7/8 inches. The outlet pipes are totally embedded in dam and encasement concrete except where they are exposed at expansion joints and at hollow-jet valves.

The outlet pipes have 6-inch gate bypass and filling piping systems at the ring-follower gates. These systems provide complete flexibility of outlet pipe filling and ring-follower gate bypass for each pair of outlet pipes. That is, pipes No. 1 and 2 may be filled from each other, and pipes No. 3 and 4 may be filled from each other; but there is no connection between pipes No. 1 and 2 and pipes No. 3 and 4.

A teetering section with double-end expansion joints was installed in each outlet pipe across the joint between the dam and the adjacent mass concrete. Sleeve-type coupling joints were located at each contraction joint in mass concrete encasements and discharge valve structure.

(b) *Design.*—The outlet pipes were designed for static head when the reservoir water surface is at maximum elevation 3711.0. For design considerations no water-hammer head was superimposed on static head because the outlet pipe gate and valve controls do not operate rapidly enough to cause significant water hammer.

The maximum designed discharge through each outlet pipe is 3,750 cubic feet per second. The corresponding average velocity in the 8-foot-diameter pipes is 74.60 feet per second. The pipe diameter was chosen for best balance between factors representing desired discharge, energy dissipation, and maximum allowable velocity short of destructive cavitation and vibration. The maximum designed velocity of 74.60

feet per second is about 10 feet per second faster than that used in previous outlet pipe designs.

The special double-end expansion joints previously mentioned were designed to accommodate calculated deflections of the dam amounting to 1-1/4 inches downstream, 1 inch vertically downward, and 1 inch laterally at the point where the pipes emerge from the dam. Sleeve-type couplings were designed by the subcontractor, R. H. Baker and Co.

Outlet pipe sections, including expansion joints and stiffener rings, were fabricated of steel plates conforming to ASTM Designation A 201, grade B, firebox quality. Middle rings and sealing glands of sleeve-type couplings were fabricated of steels conforming to ASTM Designations A 212, grade B, and A 7, respectively.

All permanent joints were welded, excepting flanged connections to ring-follower gates which were embedded in concrete. All girth and longitudinal welds in outlet pipe shells, expansion joint inner and outer sleeves, and sleeve-type coupling middle rings were fully radiographed in accordance with section VIII of the ASME Boiler and Pressure Vessel Code at that time current. Code basic design working unit stresses ASTM A 201 and 212 steels used were 15,000 and 17,500 pounds per square inch, respectively. Joint efficiency was 90 percent for both steels.

Completed sections of outlet pipes, including expansion joints and sleeve-type couplings, were hydrostatically tested at pressures computed from the formula:

$$P = \frac{43,000T}{D}$$

where:

- P = test pressure in pounds per square inch,
- T = minimum thickness, in inches, of plate course in section tested, and
- D = inside diameter of pipe in inches.

A 20-inch inside-diameter manhole is located immediately downstream from the ring-follower gate of each outlet pipe. Another similar manhole is located in the teetering section at the joint between the dam and adjacent mass concrete.

Outlet pipe No. 3 only has seven piezometer orifice stations distributed along its entire length. Piezometer orifices at each station are manifolded, and

single 3/4-inch pipes lead from each manifold to terminal boxes embedded in concrete faces in the ring-follower gate chamber, the downstream face of the dam, or the discharge valve structure. The piezometer installation is shown on figure 124.

(c) *Installation and Coating.*—The outlet pipe sections were installed under the prime contract. Interior surfaces were coated with coal-tar primer and coal-tar enamel. Exterior embedded surfaces were not coated. Exterior surfaces exposed in the teetering section vaults were coated with phenolic-resin aluminum paint.

53. 96-INCH HOLLOW-JET VALVES AND CONTROLS. (a) *Description.*—Four 96-inch hollow-jet valves and two sets of controls are provided at the discharge end of the river outlets to regulate the flow of water up to a maximum reservoir head of 536 feet. The hollow-jet valves were manufactured by Goslin-Birmingham Manufacturing Co., under invitation No. DS-5363. The controls were manufactured by the Rucker Co., under invitation No. DS-5503.

The hollow-jet valves and controls are located at the discharge end of the river outlets as shown on figures 125 and 126. A set of controls is located on a concrete platform above and between each pair of hollow-jet valves.

(1) *Hollow-jet valve.*—The hollow-jet valve is of cast and welded steel construction and consists basically of a circular body and movable concentric needle which forms an annular passage and seals in the entrance throat. The hollow-jet valve is hydraulically operated by a cylinder within the annular passage which is concentrically positioned by six radial splitters as shown on figure 126. The cylinder is 58 inches in diameter and the needle has a travel of 33-1/2 inches from fully open to fully closed position. As the valve is opened, water flows past the periphery of the needle in the shape of a cylindrical ring along the inside of the valve body. The splitters cut the ring into sectors and the water discharges from the valve in six separate jets. The estimated weight of each hollow-jet valve is 135,000 pounds.

(2) *Controls.*—Each control cabinet is of steel construction and encloses the control system for two hollow-jet valves. A cable-driven dial-type position indicator, for each hollow-jet valve, is located on the cabinet control panel to show the percentage of valve opening. Two 850-gallon oil tanks are located adjacent to the control cabinets.

An oil level gage is located on the side of each oil tank. The estimated weight of each control system is 7,300 pounds.

(b) *Design.*—

(1) *Hollow-jet valve.*—The hollow-jet valve was designed to regulate the discharge from the 96-inch outlet pipes under any head up to 536 feet. The plunger capacity was based on the sliding friction of the plunger and packings, and the hydrostatic force from full reservoir head acting on the upstream face of the needle. V-type packings are provided to minimize leakage past the plunger. Stainless steel seats are provided on both the upstream body and the needle. Stainless steel cladding was used on the exterior surfaces of the plunger to prevent rusting.

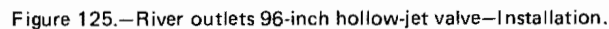
(2) *Controls.*—The hydraulic controls were designed to operate at 850 pounds per square inch for closing and 500 pounds per square inch for opening. The equipment in each cabinet consists of two oil pumps, each having a capacity of approximately 24 gallons per minute when pumping oil at 1,000 pounds per square inch; two 15-horsepower, 440-volt, 3-phase, 60-cycle electric motors; connecting piping; and hydraulic and electric controls. Remote controls were not provided.

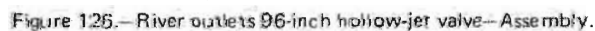
(c) *Design Stresses.*—

(1) *Tensile.*—The allowable design stresses in tension for the following materials were based on the yield point or the ultimate tensile strength of the material. The smaller of the tabulated values was used in each instance:

Material	Type	Percent of yield point	Percent of ultimate tensile strength
Steel	Rolled or forged	40	25
Bolt steel	Rolled or forged	25	16.5
Cast steel	Castings	33	20
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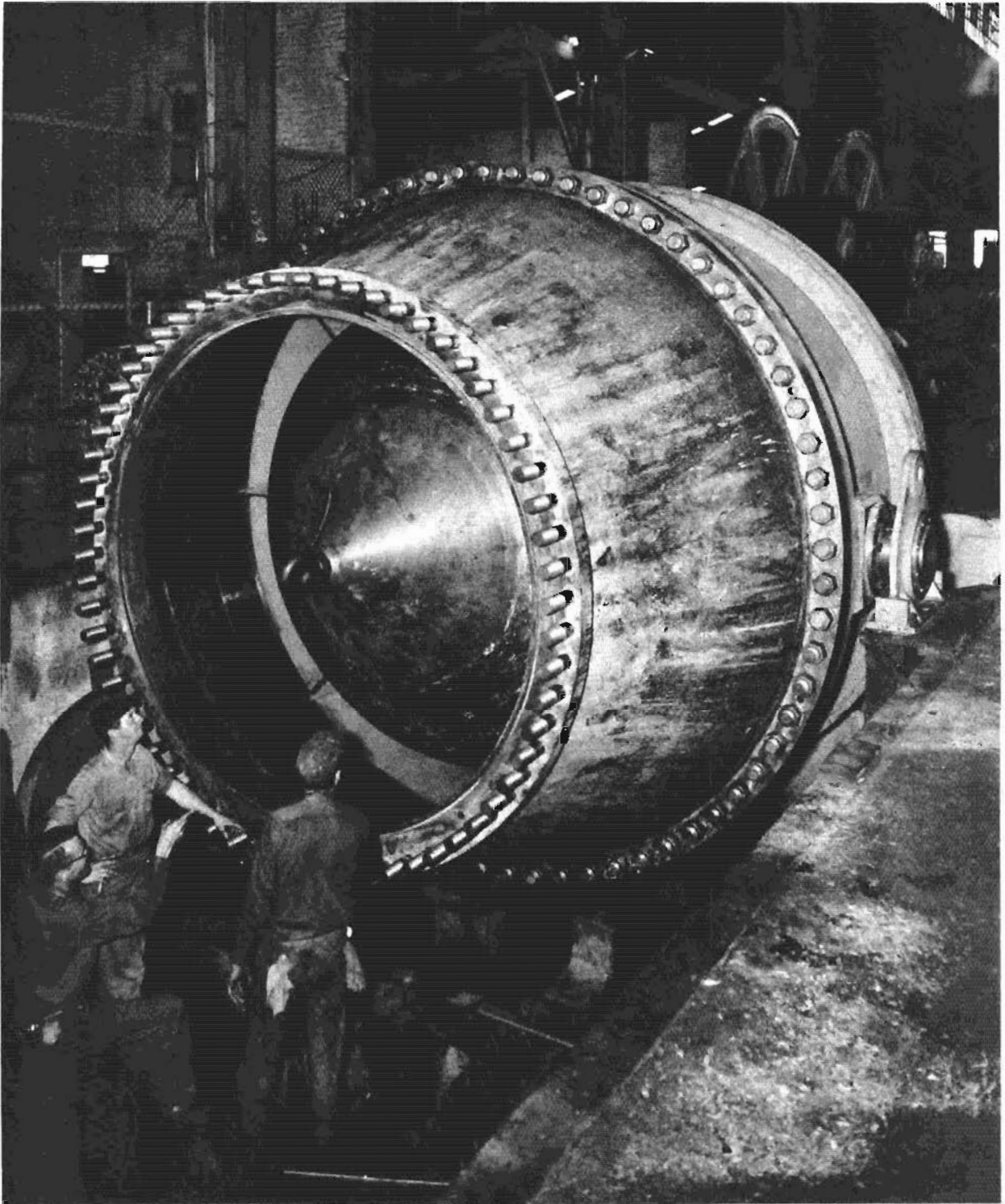


Figure 127.—Downstream view of 96-inch hollow-jet valve.

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(2) *Compression*.—The allowable design stresses in compression used for the materials listed above were the same as for tension.

(3) *Shear*.—The allowable design stresses in shear were not more than 0.6 the allowable design stresses in tension.

(4) *Structural steel*.—Allowable design stresses for structural steel in tension or compression were not more than 20,000 pounds per square inch. In general, structural steel stresses were based on the American Institute of Steel

Construction "Specifications for the Design, Fabrication, and Erection of Structural Steel for Buildings," 1961.

(5) *Hoist cylinder*.—The allowable design stresses for hoist cylinders were based on the recommendations of the ASME Boiler and Pressure Vessel Code—Unfired Pressure Vessels—Section VIII.

Figure 127 shows a downstream view of the 96-inch hollow-jet valve and figure 128 shows a front view of the 96-inch hollow-jet valve control cabinet.

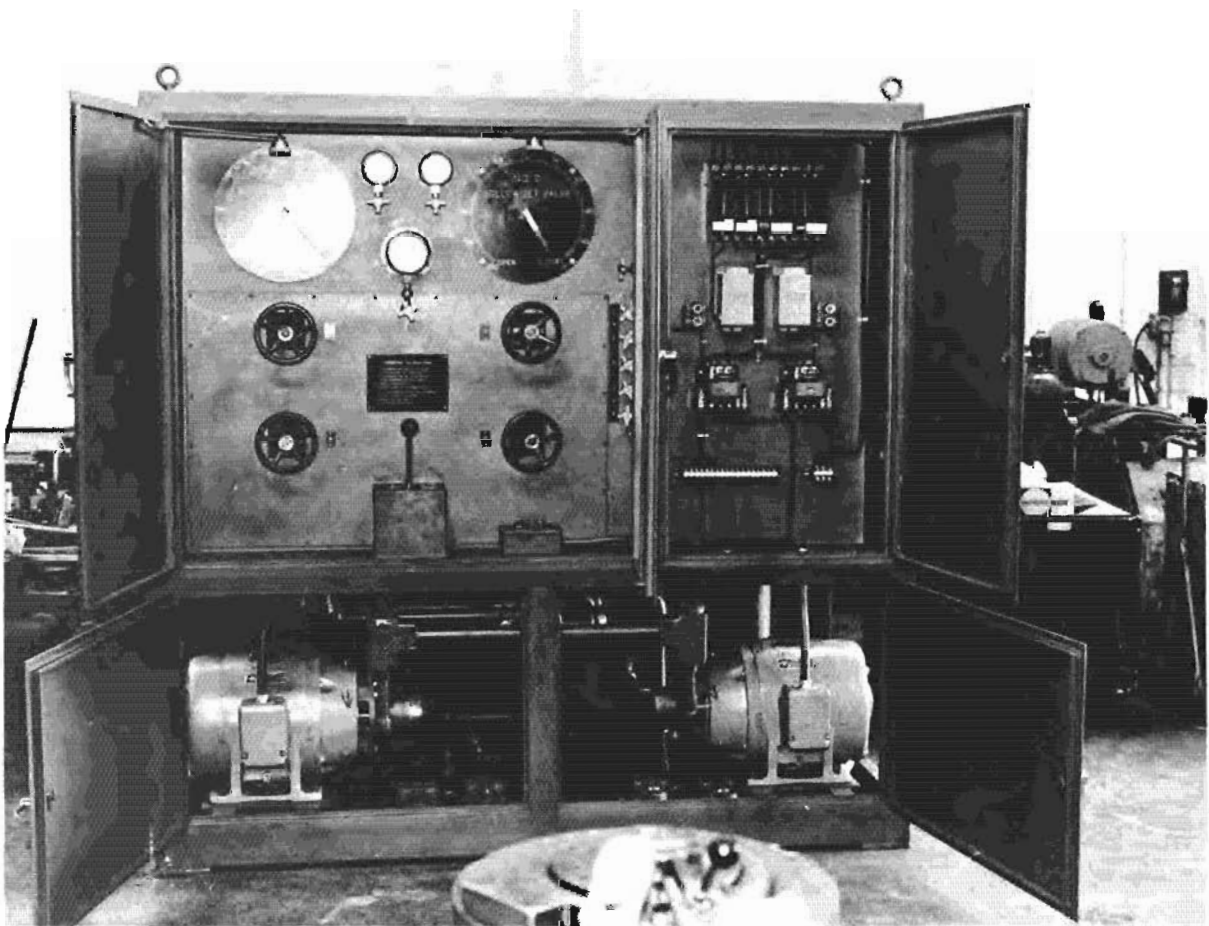


Figure 128.—Front view of 96-inch hollow-jet valve control cabinet. P557-D-31840.