CHAPTER VII. *Design*—POWER WATERWAYS

54. LOCATING PENSTOCKS. (a) *General.*—Eight 15-foot-diameter steel penstocks for delivering water to the turbines in the powerplant are embedded in the dam (figs. 129 and 130). The centerline of each penstock intake is at elevation 3470 which is about 45 feet above estimated silt elevation after 150 years of reservoir operation. The minimum water surface for power operation is elevation 3490. A 13.96- by 22.45-foot fixed-wheel hydraulically operated closure gate which can operate under unbalanced head was provided at the upstream face of the dam for each penstock. An unlined transiton section from rectangular to round was provided at the entrances of the penstocks for a smooth increase in flow velocity and to reduce the width required for each closure gate (fig. 131). A reinforced concrete trashrack structure (fig. 132), with structural steel trashracks, protects the entrances. Guides and seats for stoplogs were installed upstream from the closure gate to provide a means for inspecting the gate frames and guides if required. Special joints to take movement in three directions were designed for the penstocks, where they leave the dam, to provide for movements of the dam under variable load. These joints were set in special vaults at the toe of the dam (fig. 133). The penstocks are supported between the dam and the powerplant on reinforced concrete piers which, in turn, are carried to bedrock (figs. 134 and 135). The backfill in the area between the dam and powerplant was placed above the top of the penstocks, and a drainage system was provided as shown on figure 83.

(b) *Layout.*—The layout of the penstocks in the dam was dependent upon the following criteria:

(1) The penstocks had to be radial at the upstream face of the dam, and so located that the trashrack structures did not cross contraction joints.

(2) The minimum distance from the centerlines of the penstocks to the radial contraction joints in the dam had to be at least one and one-half pipe diameters.

(3) There were to be no bends in the penstocks between the dam and the powerplant.

(4) The minimum permissible bend radius was to be four pipe diameters.

(5) The spacing of the generators in the powerplant was to be 65 feet on centers.

In addition to the above criteria, there were limits to the permissible spacing of the contraction joints in the dam. To preclude difficulties in cooling of the blocks and grouting of the contraction joints, the minimum and maximum block widths, measured along the axis of the dam, were 40 and 70 feet, respectively. The layout criteria were satisfied by selecting a system of blocks using maximum and minimum permissible widths, bending two of the penstocks inside the powerplant structure, and anchoring horizontal bends to the mass concrete in the dam where the bends were near the downstream face of the dam.

55. STRUCTURAL DESIGN. (a) *General.*—The design 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 pipe in the dam was increased to 25,000 pounds per square inch.

(b) *Trashrack Structures.*—The concrete trashrack structures were designed for a differential waterload of 20 feet, temperature effects, and dead load. The gate guide supports were designed for unwatering the gate guide area with normal water surface.

(c) *Gate Hoist Structure.*—The gate hoist structure was designed for the following conditions:

(1) A 25° F. temperature change.

(2) A 20-foot differential waterhead around structure and 5° F. temperature change.

(3) Stoplogs in place—water on sides—thrust from stoplog seats.

(4) A pullout hoist load of 668,000 pounds which included the force to overcome any jamming of gate during lifting operation.

The gate hoist structure has a removable cover (see fig. 136). For details of the gate hoist structure see figure 137.

(d) *Gate Hoist and Stem Storage Platform.*—The gate hoist and stem storage structure is shown on figure 138. It was designed to store the gate hoist and the
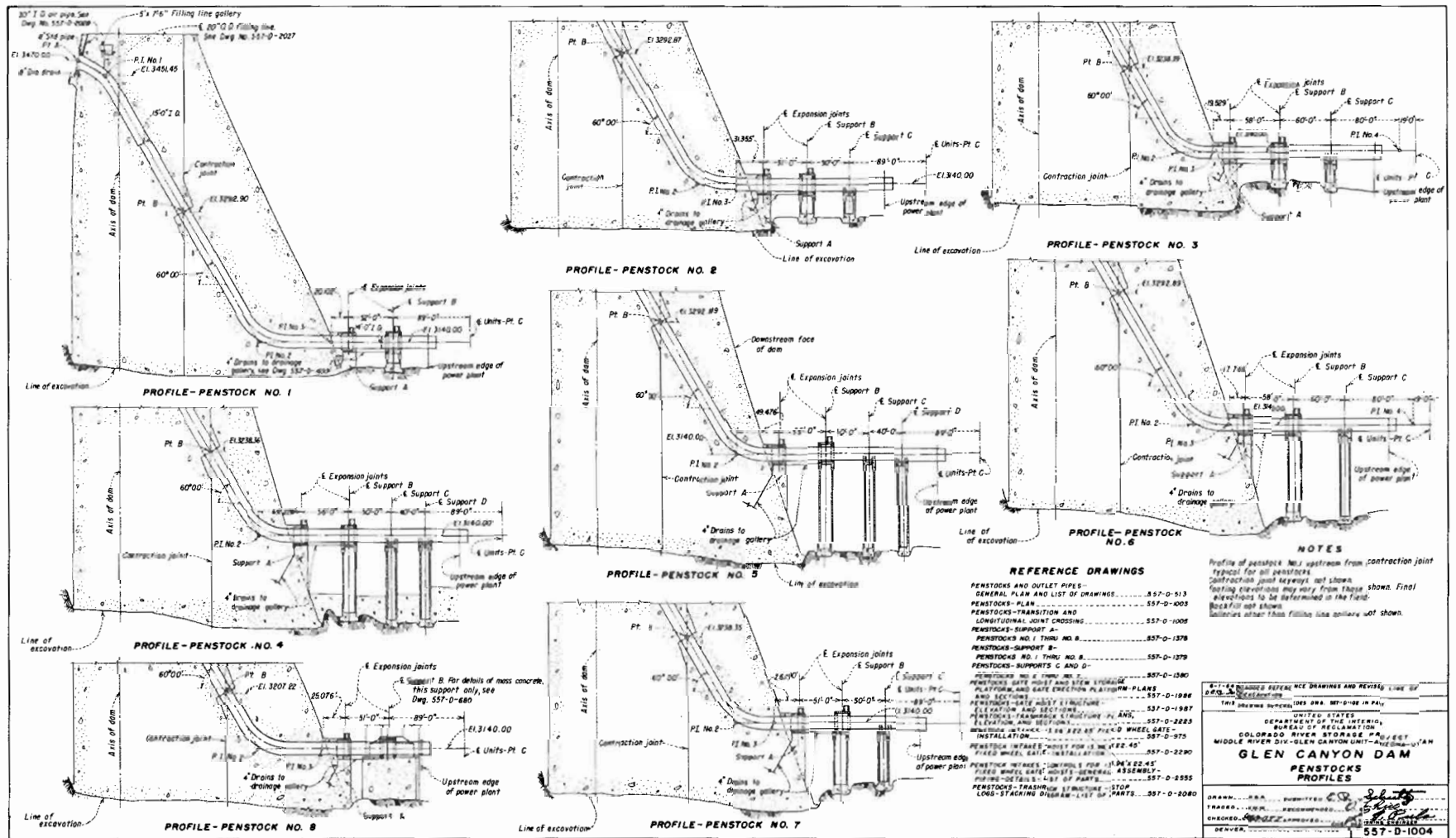
Figure 129.—Plan of penstocks.

Figure 130.—Profile of penstocks.

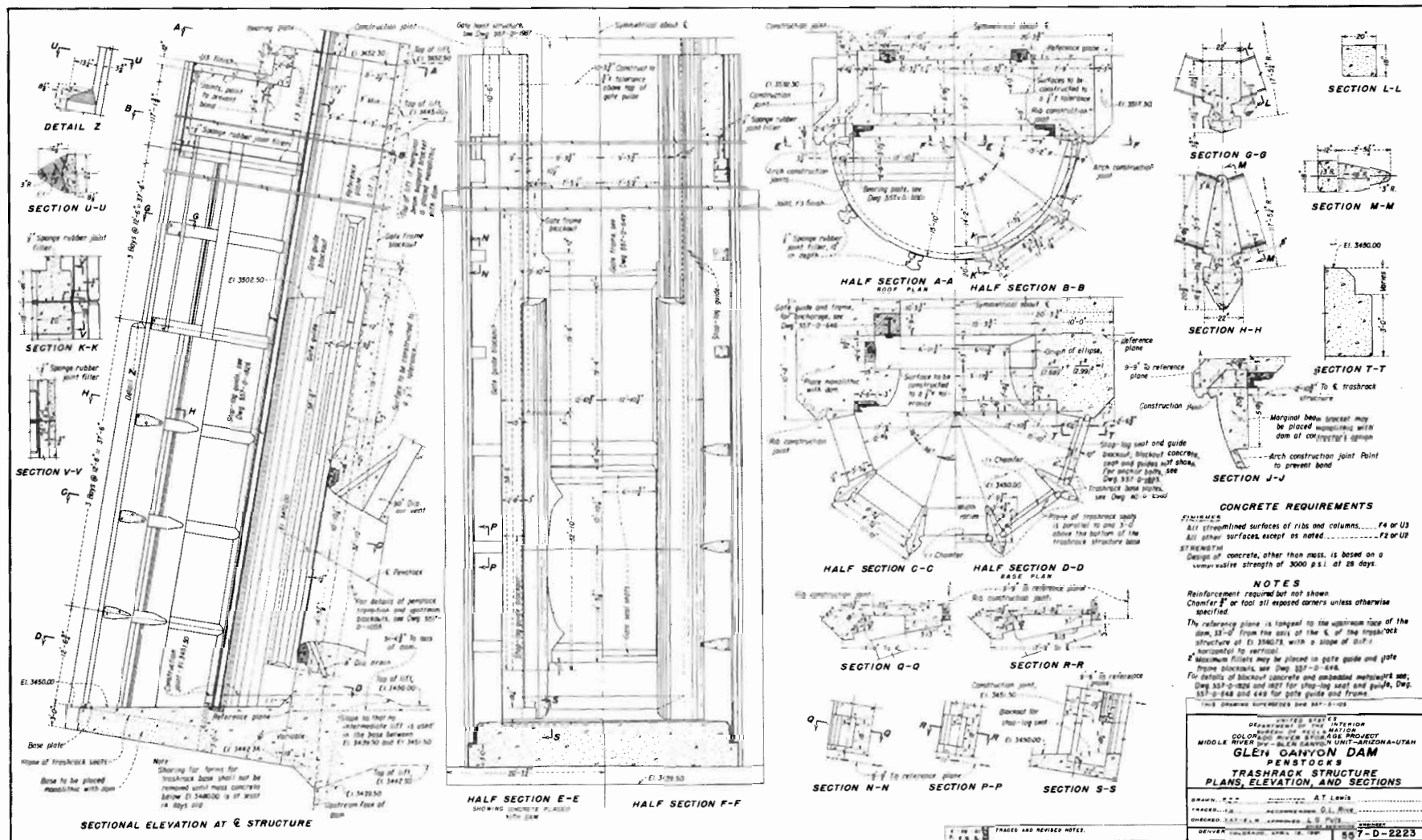Figure 131.—Penstocks—Transition and longitudinal joint crossing.

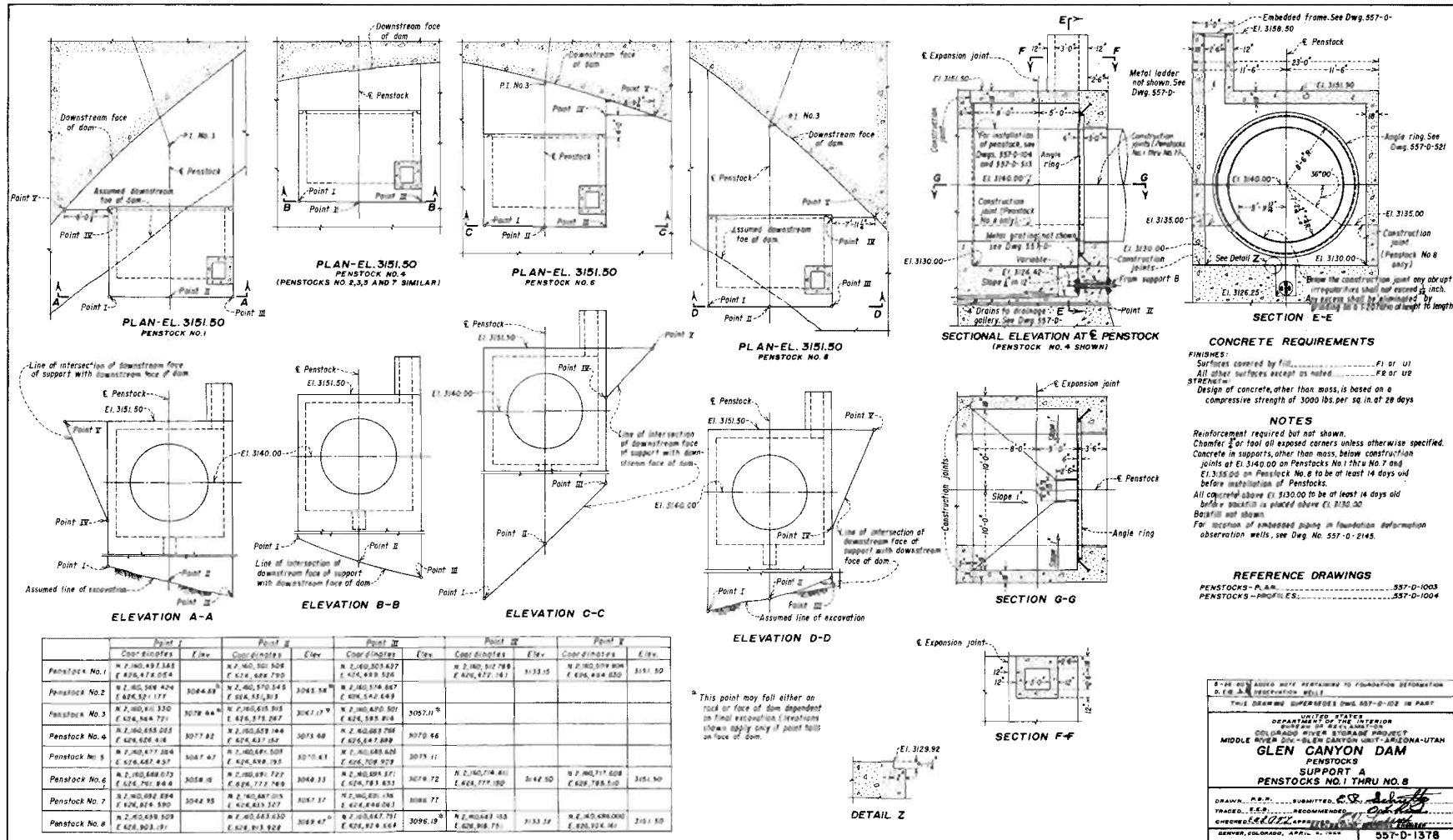Figure 132.—Penstocks trashrack structure—Plans, elevation, and sections.

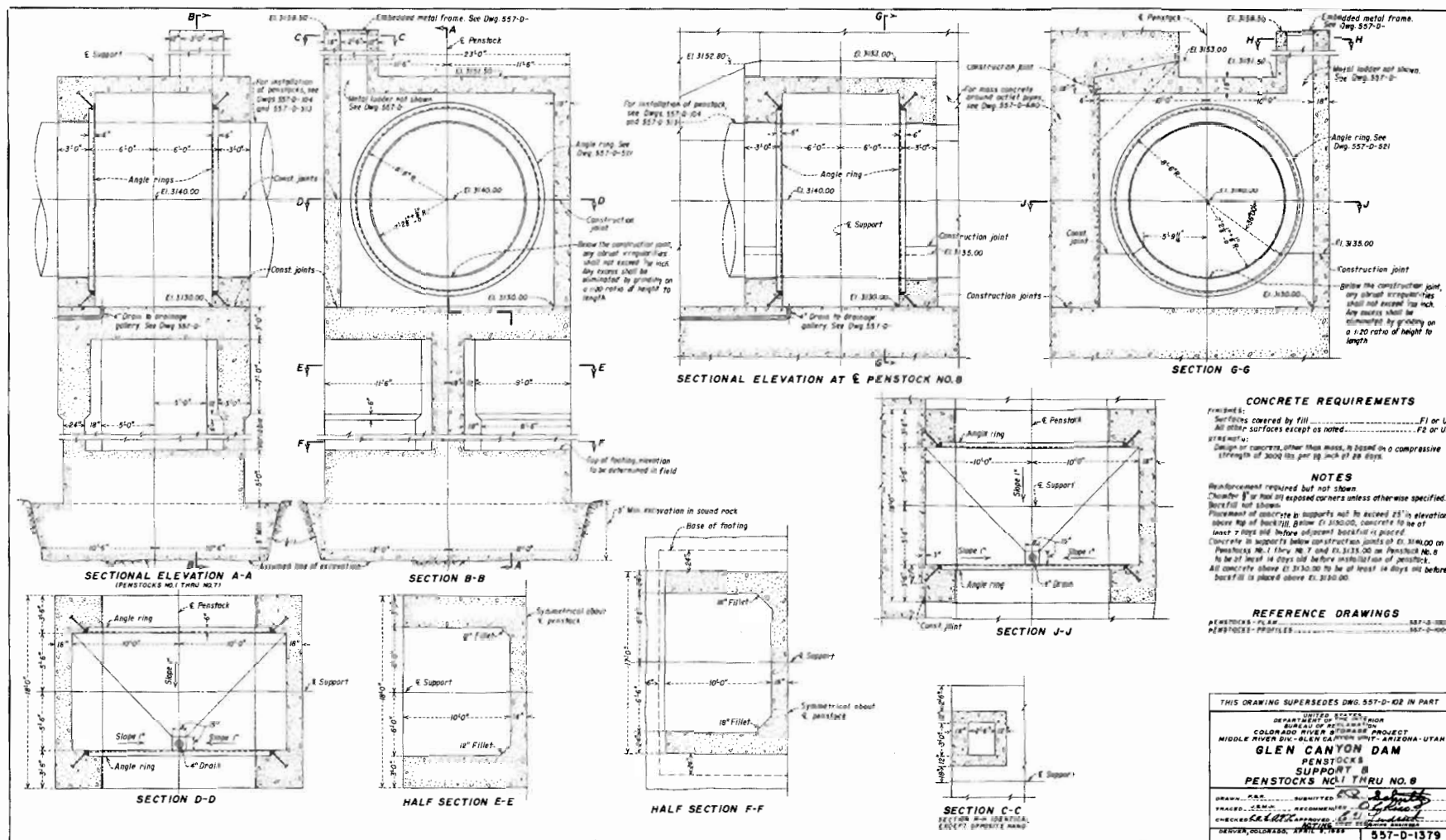Figure 133.—Penstocks No. 1 through No. 8—Support A.

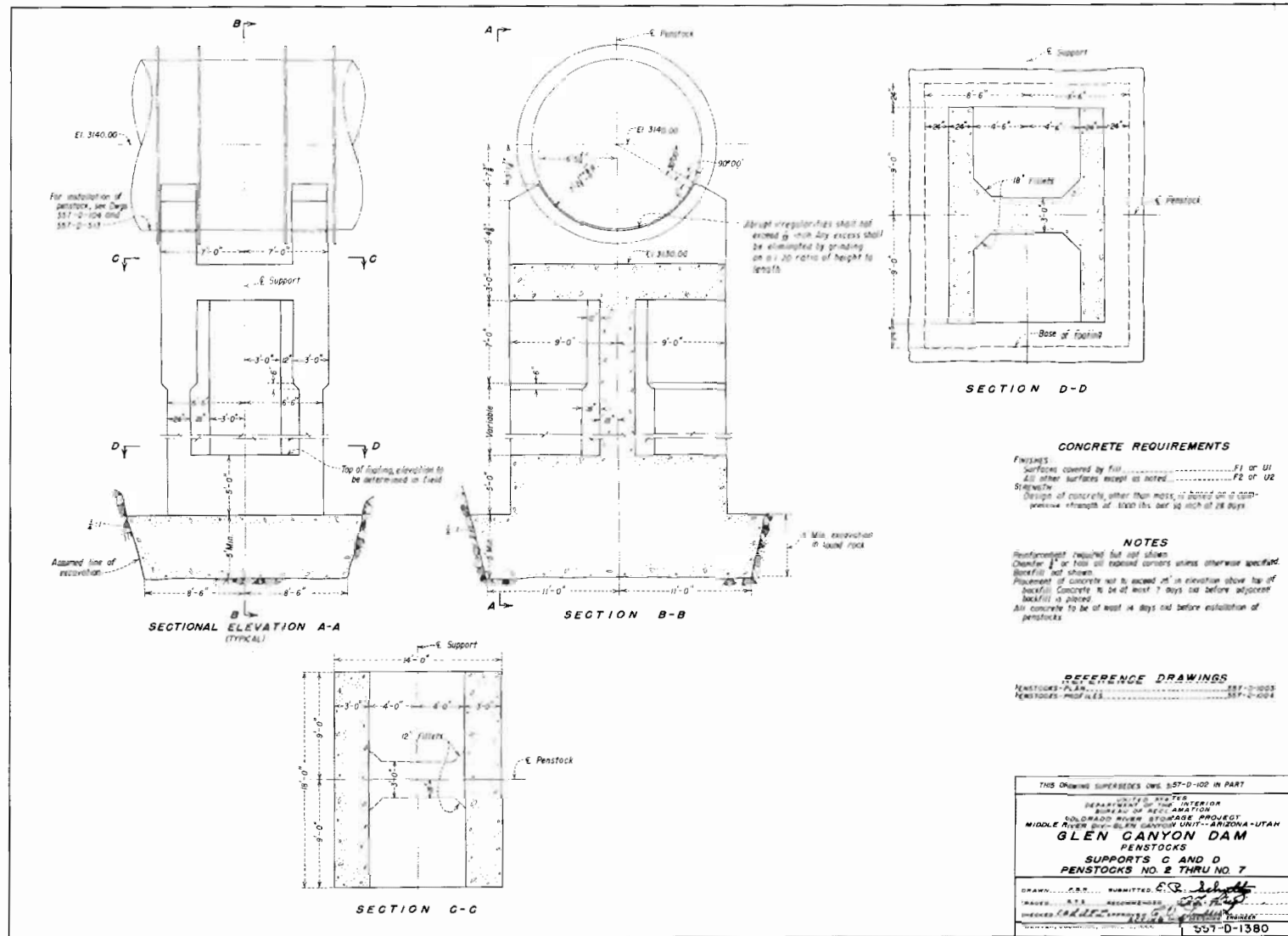Figure 134.—Penstocks No. 1 through No. 8—Support B.

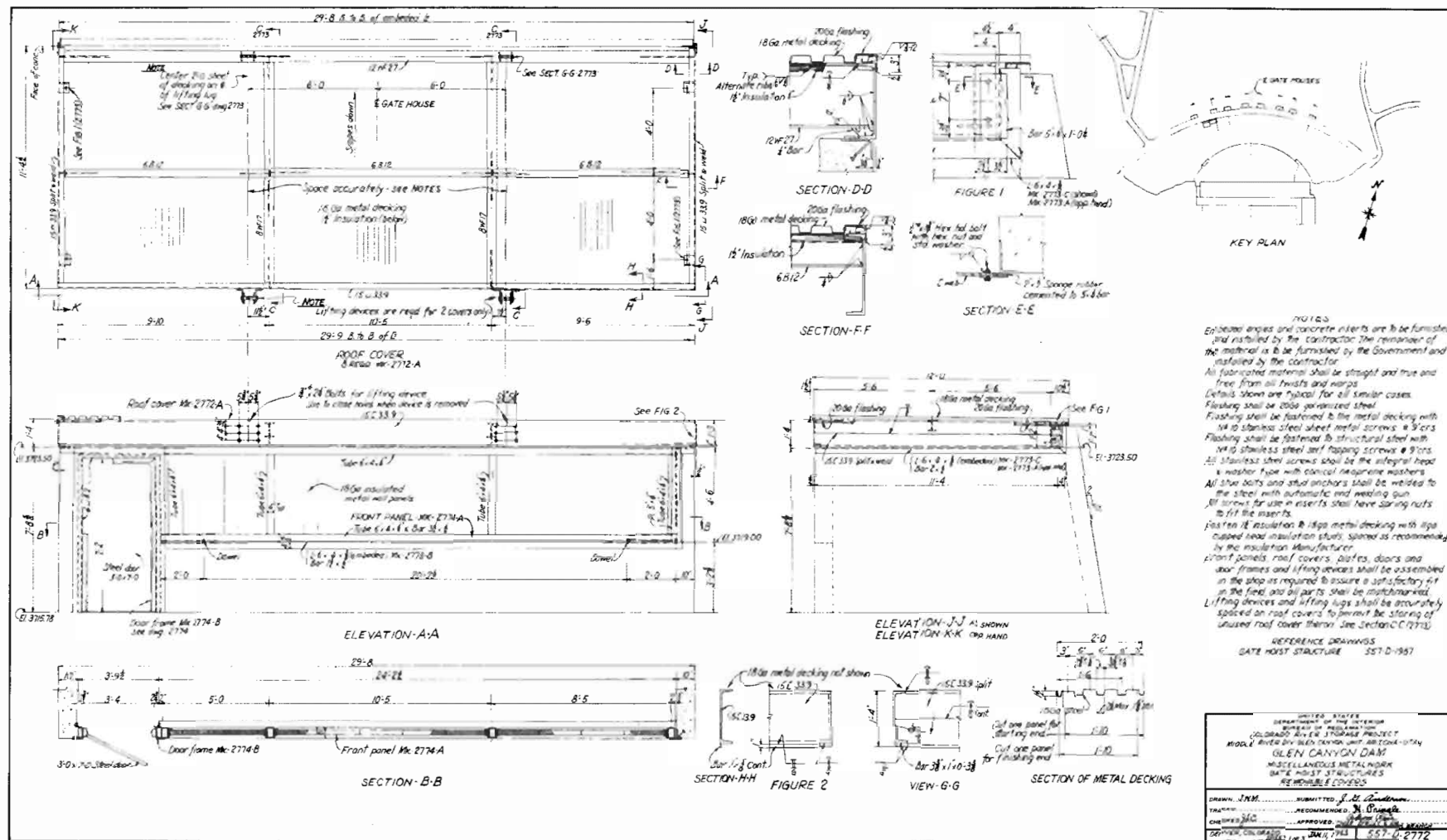Figure 135.—Penstocks No. 2 through No. 7—Supports C and D.

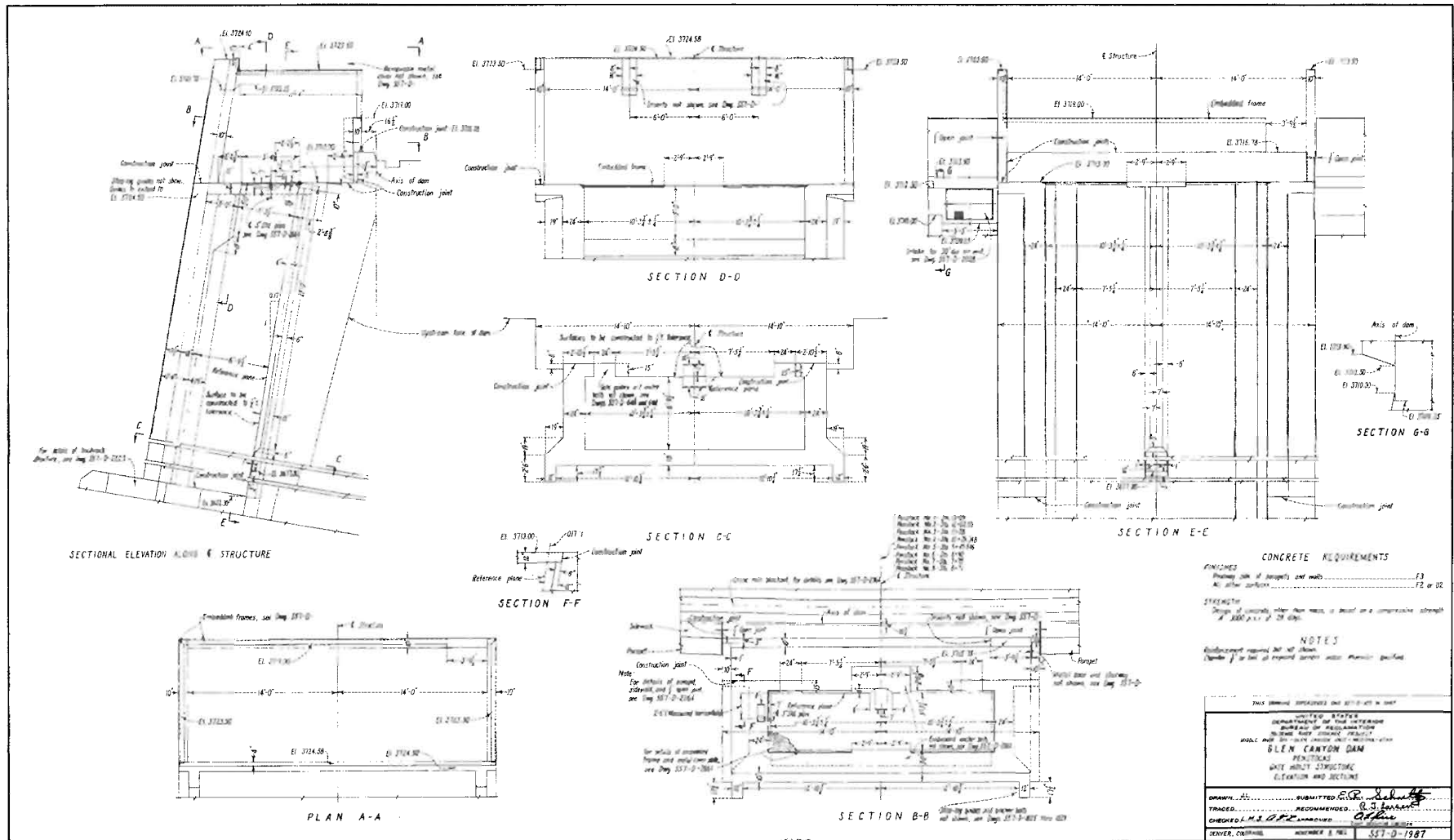Figure 136.—Miscellaneous metalwork—Gate hoist structures removable covers.

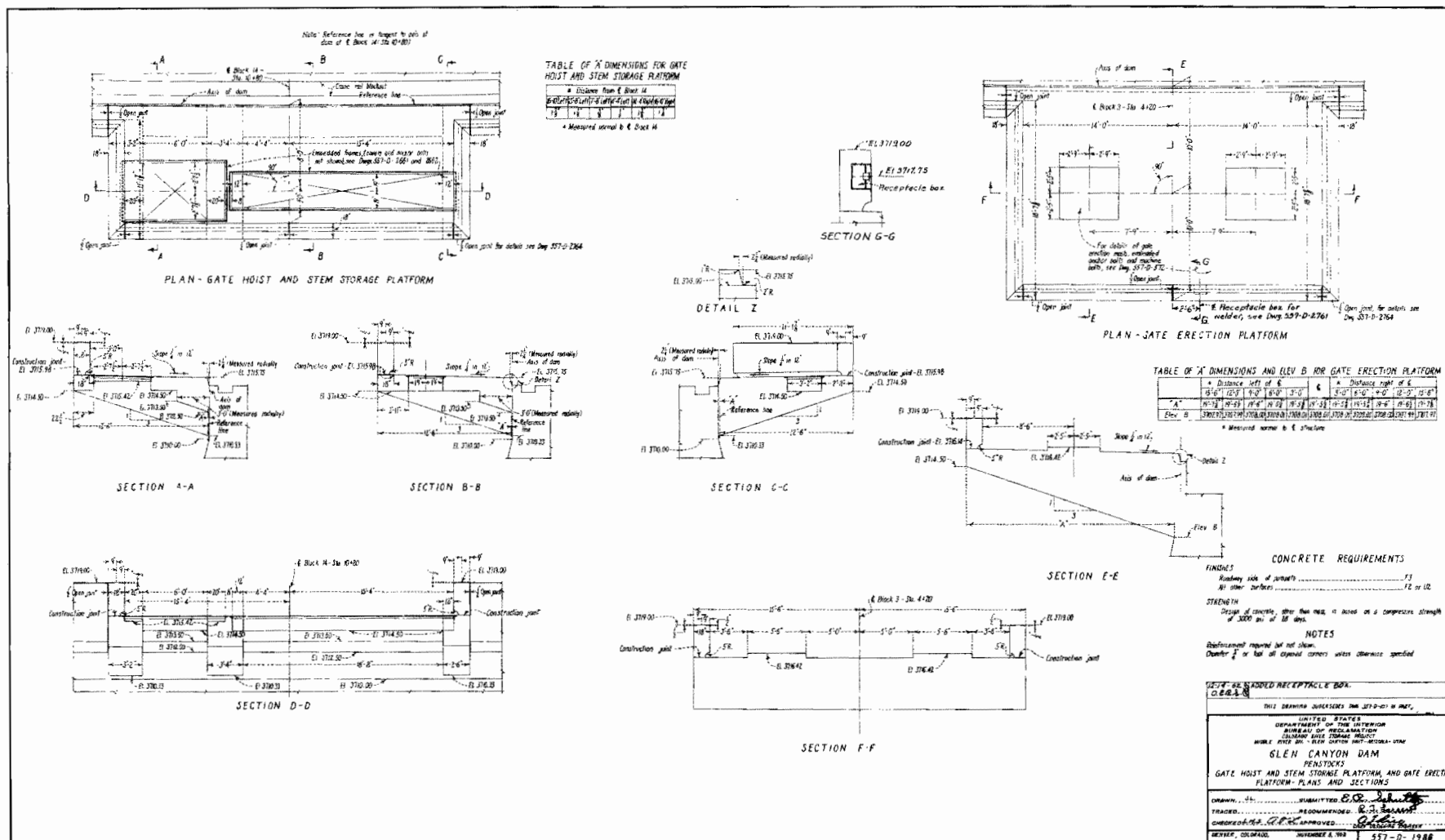Figure 137.—Penstocks gate hoist structure—Elevation and sections.

Figure 138.—Penstocks gate hoist and stem storage platform, and gate erector platform--Plans and sections.

hoist stems when a penstock fixed-wheel gate is being serviced. The structure was designed to support its own weight as well as the dead load weights of the gate hoist and stems.

(e) *Gate Erection Platform.*—The gate erection platform is also shown on figure 138. It was designed for the erection and servicing of the penstock fixed-wheel gates and the river outlet bulkhead gate. The river outlet bulkhead gate will be stored on the platform.

(f) *Penstock Concrete Reinforcement.*—The reinforcement requirements for the penstocks were broken into three sections, as follows:

(1) The approximately 21-foot-long upstream transition which has no steel liner.

(2) The circular section with steel liner extending from the downstream end of the transition to a point approximately 30 feet upstream from the downstream face of the dam.

(3) The circular section with steel liner from a point 30 feet upstream from the downstream face to the downstream face of the dam.

Since the transition section has no steel liner, cracks could open into adjacent galleries and openings which could result in excessive leakage. In order to control cracking, the transition section was reinforced for tensile forces caused by dam stresses, internal bursting pressures, and temperature effects.

The circular section with steel liner, except the approximately 30-foot-long downstream section, has enough mass concrete cover that tension cracks cannot propagate to the surface of the dam. There is no leakage problem since the penstock has a steel liner. Therefore this section of the penstock was reinforced only for tensile forces caused by dam stresses and temperature effects.

The downstream approximately 30-foot section presents no leakage problem since it has a steel liner; however, tension cracks could open to the downstream face of the dam in the area. In order to control cracking this section was reinforced for tensile forces due to dam stresses, temperature effects, and internal bursting pressure, including waterhammer effects. In addition, anchorage reinforcement was provided for the unbalanced forces in the horizontal bends in this area.

(g) *Supports.*—The supports shown on figures 129, 130, 133, 134, and 135 consist of the following component parts:

(1) Vaults (two upstream supports) or bearing walls

(2) H-column

(3) Footing

The vaults were designed for the following loads:

(1) Dead load of structure

(2) Backfill to elevation 3157

(3) Temperature effects

(4) Earthquake effects

(5) Penstock reactions

The bearing walls on the supports without vaults were designed for the following loads:

(1) Temperature effects

(2) Earthquake effects

(3) Penstock reactions

The overall dimensions of the H-columns were determined in part by the vaults or supporting walls above. The length to depth ratio was kept within the short column range. The individual legs of the H-column were given a small length-to-depth ratio to prevent buckling.

The H-column and its members individually were designed for the following loads:

(1) Dead weight from above

(2) Penstock reactions

(3) Earthquake effects

The footings were stepped with the top part having the same exterior dimensions as the H-column and the bottom part widened in both directions to increase stability and reduce foundation stresses.

The footings were designed for the following loads:

(1) Dead loads.

(2) Penstock reactions.

(3) Fill material (partly saturated).

(4) Earthquake effects.

A minimum of 1 percent of vertical reinforcement was placed in the H-columns.

56. TAILRACE TRAINING WALLS. Tailrace training walls are provided on each side of the tailrace downstream of the powerplant. On the left side of the upstream 75 feet of the wall is a gravity section and the rest of the wall is cantilevered off the mass concrete under the river outlets and hollow-jet valves. It is shown on figure 114. It also serves as a retaining wall to retain the fill for the powerplant parking area. The right training wall is of the line-drilled type and was doweled to the rock, figure 139.

The left training wall was designed for the following loads:

(1) Parking area fill material (saturated).

(2) 100-ton trailer unit including impact from bumping curb.

(3) Earthquake effect.

57. TAILRACE SLAB. To insure a minimum tailwater for the turbines, a tailrace slab (fig. 140) was constructed between the tailrace walls. This slab sloped up on a 6 to 1 slope from the draft tubes to form a weir at elevation 3132, 180 feet downstream of the powerplant. From the weir the slab sloped down until it was approximately 20 feet below riverbed. It was originally planned that the tailrace channel and weir would be constructed of riprap, but lack of suitable rock within economical haul distance dictated the change to a reinforced concrete slab. The riprap weir was tested in a hydraulic model.[1]

The maximum drawdown rate of the tailwater over the weir was established at 10 feet in 10 minutes. Studies showed that porous concrete drains at 10-foot centers each way provided adequate relief from uplift pressures so that, in general, an 8-inch slab would be stable. Near the left training wall, studies indicated that saturation of the fill and bedrock behind the wall caused higher uplift adjacent to the wall and the slab thickness was increased to 12 inches. At the weir, the slab was made 12 inches thick to provide additional stability for the weir.

During the April through July runoff period in 1965, discharges up to 50,000 cubic feet per second were released in order to obtain a rated head at Lake Mead and maintain Lake Powell at about elevation 3490. The discharge was obtained by using combinations of the discharges from the turbines, the diversion tunnel outlets, and the river outlets. The river outlets were used to their design capacity when the tunnel outlets were closed.

During the night of April 20, 1965, the slab was undermined and portions of it sank from sight. At the time of the failure the reservoir water surface was at about elevation 3490, four of the eight units in the powerplant were operating, the diversion tunnel outlets and outlet No. 1 were closed, outlet No. 2 was 25 percent open, outlets No. 3 and 4 were 90 percent open, and the tailwater was 4 to 6 feet lower than had been predicted and used in the model studies. Operating the river outlets at reservoir water surface elevation 3490, instead of at normal water surface elevation 3700 as used in the model, caused the jets to impinge closer to the weir.

Observation of flows in the tailrace area, after the failure, showed a reversal of flow due to a large eddy extending to the location of the weir. This reverse flow had an unexpected velocity estimated to be 15 feet per second. The operation of the outlets at the lower head, operation of only four powerplant units instead of eight, and the lower tailwater all intensified the eddy action over that predicted from the model. The scour from this reverse flow, caused by the large eddy, undermined the toe of the slab and rapidly removed large amounts of fine bedding material, causing collapse of the slab. The extensive use of the river outlets at near full capacity with the reservoir at about elevation 3490 and with only four of the powerplant units operating had not been anticipated and had not been checked in the model.

To date (June 1969) the floor slab has not been repaired or replaced, as observation has indicated no further significant erosion in the tailrace floor.

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[1] "Hydraulic Model Studies of the Spillways and Outlet Works—Glen Canyon Dam—Colorado River Storage Project, Arizona," Hydraulic Laboratory Report No. Hyd-469, Bureau of Reclamation, February 18, 1964 (unpublished).
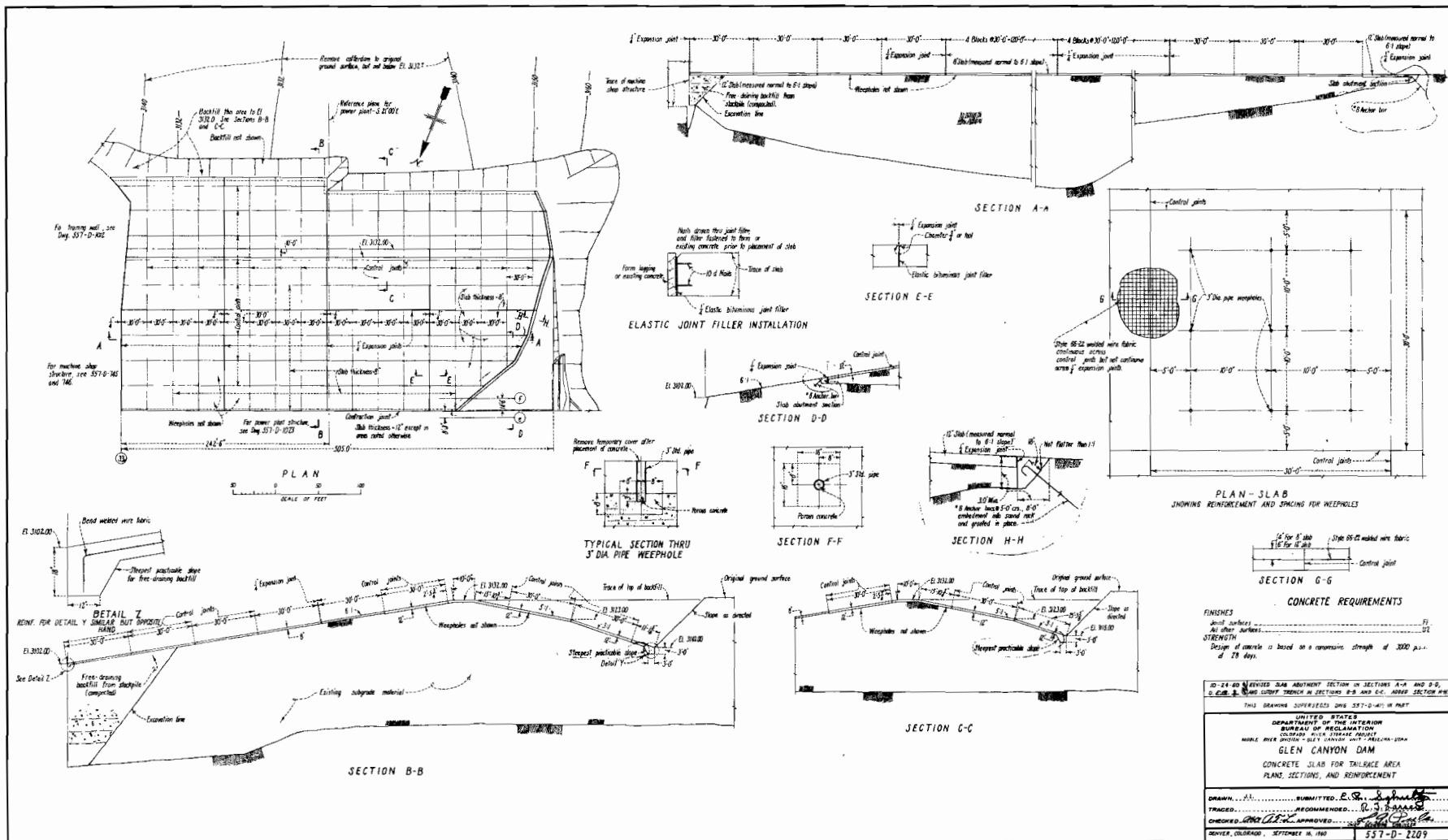
Figure 139.—Dam tailrace area—Right training wall—Plan and sections.

Figure 140.—Concrete slab for tailrace area—Plans, sections, and reinforcement.

58. PENSTOCK STEEL DESIGN. (a) *Description.*—Eight penstocks are provided to conduct water from the reservoir through the dam and to the eight turbines in the powerplant. The penstock alinements and profiles are shown in figures 122, 141, and 142. Fabrication was performed by a separate contract under invitation No. DS-5052.

The penstocks begin as 15-foot-inside-diameter pipes at the downstream ends of formed concrete rectangular-to-circular transitions in the upstream face of the dam at centerline elevation 3470.0. Extending downward toward the dam toe, they taper through reducing bends to an inside diameter of 14 feet, then level off at centerline elevation 3140.0 and emerge from the dam. Passing through fill for an average 150 feet, they then enter the powerplant. Sleeve-type coupled makeup sections 10 feet long connect to the turbine spiral cases. Makeup sections are designed and supported so that they may be disconnected and displaced laterally to permit access to penstocks for major inside inspection and maintenance. Penstocks in fill are sleeve-type coupled 50-foot sections, excepting those sections nearest the dam which are coupled with special double-end expansion joints. Penstocks in fill are supported by concrete piers which extend to bedrock. The average length of each penstock is about 610 feet. Minimum and maximum penstock plate thicknesses are 7/8 inch and 1-13/16 inches, respectively.

A 24-inch outside-diameter penstock filling header pipe extends across and above the penstocks near their upstream ends. Individual 20-inch outside-diameter valved riser pipes connect each penstock to the header.

(b) *Design.*—The penstocks were designed for a maximum total head of 695 feet including water hammer, measured at the centerlines of the generating units. The maximum designed static head is 560 feet at this point. Water hammer was calculated for the most severe combination of reservoir water surface elevation with normal discharge and a turbine wicket gate closure time of 5 seconds from full open position.

Each turbine discharge is 3,580 cubic feet per second at 450-foot rated head. The corresponding average velocities in each penstock are 20.26 and 23.26 feet per second for the 15- and 14-foot-diameter portions, respectively.

The special double-end expansion joints mentioned above in subsection (a) were designed to accommodate the displacement of the dam amounting to 2-1/4 inches downstream and 2-1/4 inches vertically downward at centerline elevation of the 14-foot-diameter pipes. Sleeve-type coupled field joints downstream from the expansion joints were also designed to allow small angular displacements in the alinements of the penstocks. The 14-foot-diameter penstock sections in earthfill were designed against flotation on the assumption of nonfluid fill material weighing not less than 40 pounds per cubic foot in water, or 102.4 pounds per cubic foot in air.

Penstock sections, including expansion joints and stiffener rings, were fabricated of steel plates conforming to ASTM Designation A 201, grade B. Middle rings and follower rings 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. All girth and longitudinal welds in penstock 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. Code basic design working unit stresses for ASTM A 201 and A 212 steels used were 15,000 and 17,500 pounds per square inch, respectively. Joint efficiency was 95 percent for both steels. All field erection sections, including expansion joints and sleeve-type couplings were furnace stress relieved in accordance with the afore-mentioned code.

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

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

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.

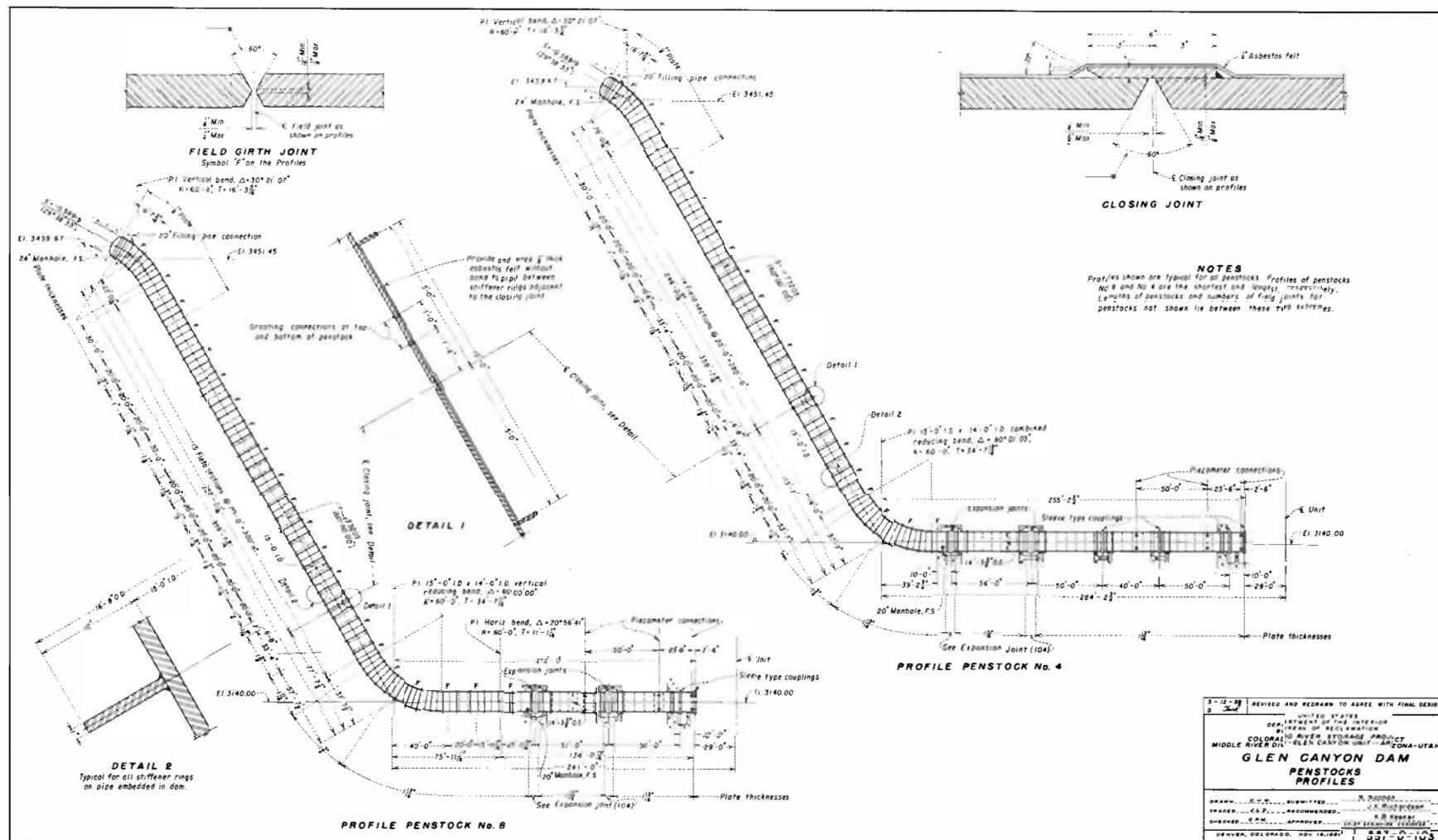A 24-inch-outside-diameter manhole is located in the first bend of each penstock. The formed inlet
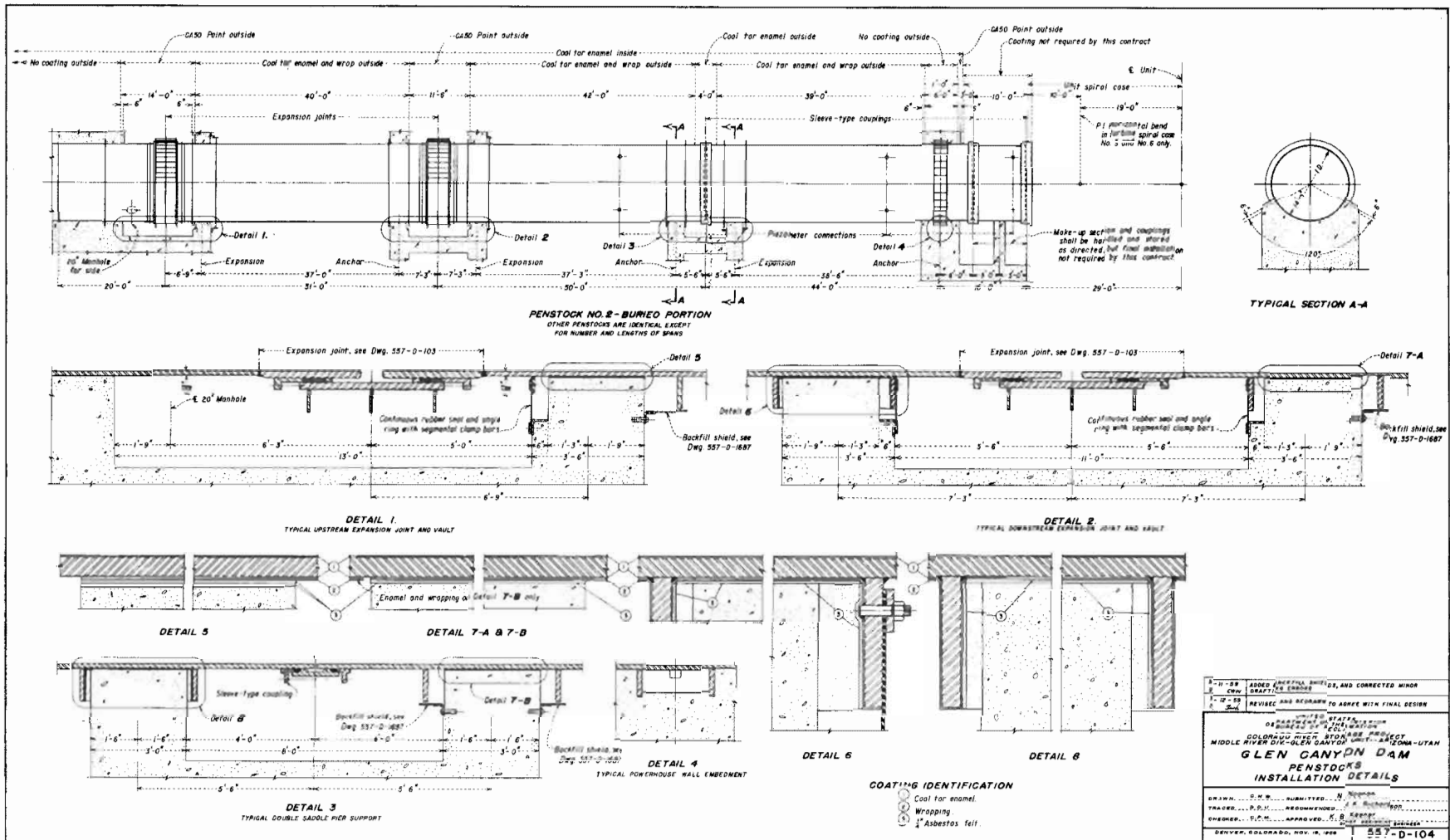
Figure 141.—Penstock profiles.

Figure 142.—Penstock installation details.

transitions may be reached by temporary ladders brought inside the penstocks through the manholes and laid on inverts. A 20-inch-inside-diameter manhole is installed in each penstock immediately upstream from the first expansion joint.

Two piezometer orifice stations 50 feet apart are located on each penstock in its level portion near the powerplant. Individual 3/4-inch pipes lead from each piezometer connection into the powerplant.

(c) *Installation and Coating.*—Penstock sections were installed under the prime contract, excepting makeup sections, which were installed under the completion contract, specifications No. DC-5750.

Interior surfaces of penstocks were coated with coal-tar primer and coal-tar enamel. Exterior surfaces in backfill, except the sleeve-type couplings, were coated with coal-tar primer, coal-tar enamel, bonded-asbestos felt, and kraft paper wrap. Exterior surfaces of sleeve-type couplings in backfill were coated with coal-tar primer and coal-tar enamel, and surrounded by sand shields. The penstock exterior embedded surfaces were not coated. Exterior surfaces of penstocks, makeup pieces, and sleeve-type couplings exposed to view in the powerplant were coated with phenolic-resin aluminum paint.

59. PENSTOCK TRASHRACKS. A total of 280 trashracks are provided for the penstock trashrack structures to protect the turbines from oversize trash. The 280 trashrack sections, approximately 9.33 feet wide by 12.5 feet high, as shown on figure 143 were furnished under invitation No. DS-5512.

The trashracks are installed in vertical slots in the penstock trashrack structures. The racks consist of 2- by 5/8-inch trash bars supported by 9- by 1-inch horizontal load carrying plates which transmit the load to the side members. The 4-3/8-inch clear opening between the trash bars conforms with the recommendations of the turbine manufacturer. The estimated weight of the 280 trashracks is 980,000 pounds.

The trashracks were designed for a differential head of 20 feet at a stress of 33,000 pounds per square inch.

60. PENSTOCK STOPLOGS. Twenty-three stoplog sections were required for the penstock intakes

to provide a bulkhead for inspection and maintenance of the fixed-wheel gates and appurtenances. One set of stoplogs, sufficient for one unit, is provided for the penstock intakes.

The following log sections were furnished for stacking in accordance with drawing No. 557-D-2080*: 9 lower log sections, approximately 24.5 feet wide by 4.80 feet high, weighing 24,700 pounds each; 7 intermediate log sections, approximately 24.5 feet wide by 5.30 feet high, weighing 25,100 pounds each; and 7 top log sections, approximately 24.5 feet wide by 6.79 feet high, weighing 27,200 pounds each. A lifting frame was also furnished for grappling purposes. All material was furnished under invitation No. DS-5354.

The stoplogs are installed in vertical guides on the face of the dam and in the trashrack structures. The stoplogs are placed in the guides in one stack. Effective sealing is obtained by means of music-note-type rubber seals bolted to the log sections.

The stoplogs were designed for a maximum head of 250 feet at safe stress.

61. 165-TON GANTRY CRANE. (a) *Description.*—A 165-ton gantry crane (fig. 274) is installed on rails on top of the dam for the installation and maintenance of penstock gates and hoists and river outlet gates and stop logs. The crane was manufactured under invitation No. DS-5521 and is an outdoor, cab-operated, electric gantry crane with a trolley supporting a 165-ton main hoist and a 25-ton auxiliary hoist.

The main hoist is reeved 6 parts double with 1-1/2-inch-diameter, 6 by 37, improved plow steel, fiber-core wire rope. The block has a lifting eye in lieu of a hook. The hoist has a lift of 53 feet, is powered by a 40-horsepower, 1,200-r.p.m., direct-current motor, and operates at incremental speeds up to 3.7 feet per minute hoisting and 4.3 feet per minute lowering with a 165-ton load.

The auxiliary hoist is reeved 2 parts double with 1-inch-diameter, 6 by 37, improved plow steel, fiber-core wire rope. The block has a sister-type hook bored for a horizontal lifting pin. The hoist has a lift of 380 feet, is powered by a 40-horsepower, 1,200-r.p.m., direct-current motor and operates at incremental speeds up to 24 feet per minute hoisting and 28 feet per minute lowering with a 25-ton load.
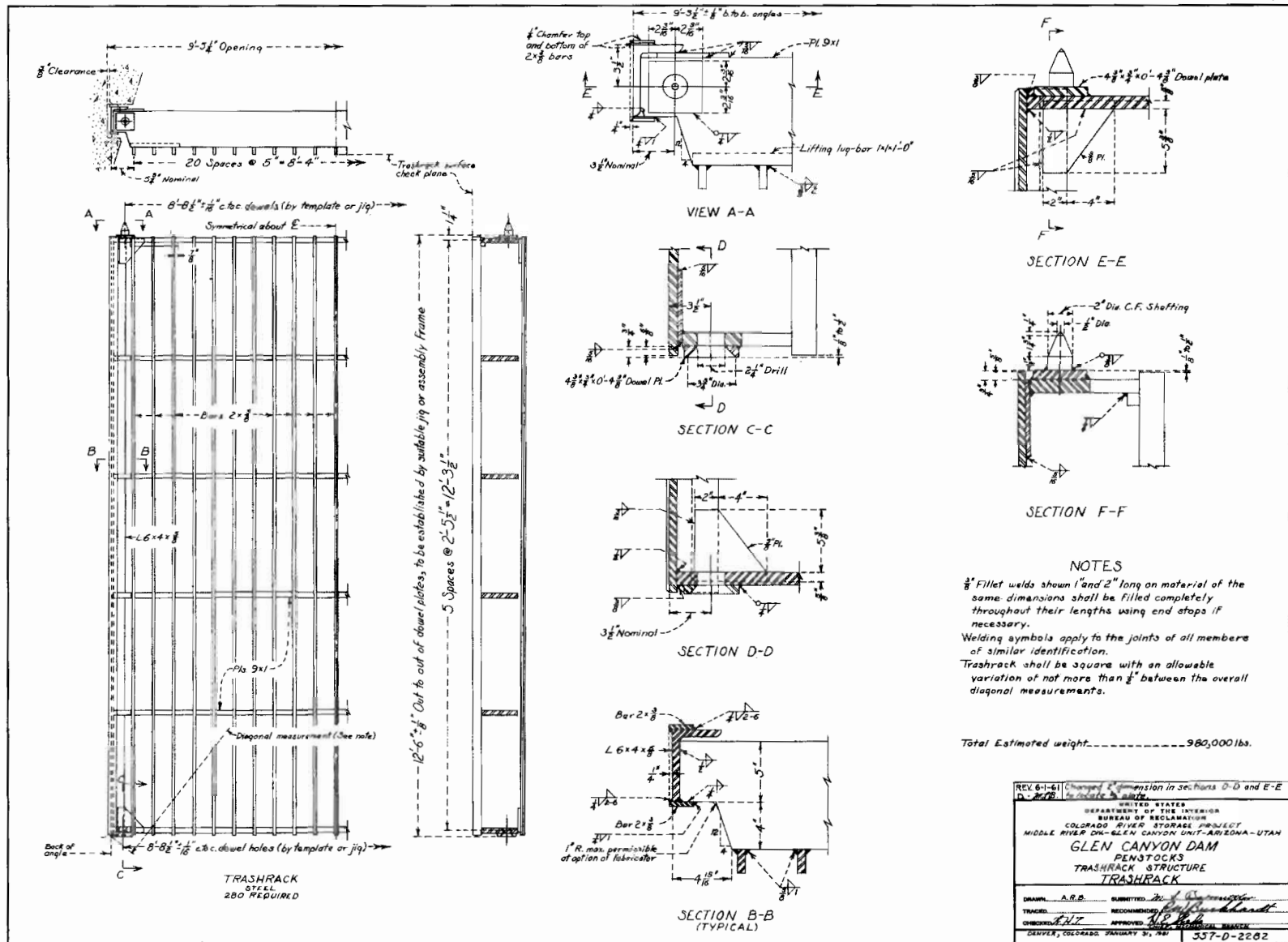
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*Not included.

Figure 143.—Penstock trashracks.

The trolley is driven by a 15-horsepower, 1,200-r.p.m., alternating-current motor at 4.8 feet per minute in either direction, through a rack and pinion drive. The gantry is driven by four 5-horsepower, 1,150-r.p.m., alternating-current motors at incremental speeds up to 48 feet per minute in either direction.

A single motor-generator set installed in the control enclosure supplies direct-current power for both hoist motors, the hoist motor controls being electrically interlocked so that only one hoist may be energized at a given time. Full magnetic controllers for each motion of the crane are located in the operator's cab. Five-point-speed control is provided for each direction of the main hoist, auxiliary hoist, and gantry drive, and single-speed control for the trolley drive.

Each hoist motor is equipped with two alternating-current magnetic brakes, one on each side of the motor, which are released when the hoist motor circuit is energized. Each of these brakes is capable of overcoming the full-load torque of the motor with which it operates. The trolley drive is equipped with a similar brake which is capable of overcoming at least three-fourths of the full-load torque of the drive motor.

Each of the gantry drive motors is equipped with a hydraulic brake, all of which are actuated by a single foot pedal located in the operator's cab. Each brake is capable of overcoming the full-load torque of the motor with which it is associated, simultaneously with the other gantry drive brakes, with no more than 50 pounds of operating force on the foot pedal. Each brake is equipped with an automatic, spring-applied, parking feature.

Block-actuated limit switches on each hoist limit the upward travel of the hook. A two-contact-geared limit switch on the auxiliary hoist limits the lower travel of the hook and lights a red light in the operator's cab. Each contact is individually adjustable within the last 30 feet of travel.

A limit switch on the main power cable reel, adjustable within the last 10 feet of cable, stops the gantry before the cable is unwound lighting a green indicating light in the operator's cab and setting the parking brake. A momentary contact pushbutton station, located near the gantry travel master switch, permits the operator to move the gantry back into the limit switch zone.

The crane is equipped with a 120-volt permanent lighting system. Service outlets are located in the operator's cab, in the control room, and on the trolley access walkway. One 100-watt lamp is installed in the operator's cab and one in the control room, each with conveniently located wall switches. Two 100-watt lamps are located on the trolley access walkway. One 750-watt narrow-beam floodlight is mounted under the trolley access walkway. Two 500-watt medium-beam floodlights are mounted on the upstream side of the crane and two 500-watt wide-beam floodlights are mounted to illuminate the roadway under the crane. There is a 240-volt, 3-kilowatt heater installed in the operator's cab.

Spring bumpers are mounted on the gantry legs at one end of the crane only. Double-acting spring bumpers are provided on the trolley. Ladders and walkways provide access to the trolley, control room, and operator's cab.

(b) *Design.*—The crane was designed according to the Navy Department's standard of design for structural steel using a base stress of 16,000 pounds per square inch. Computations of stress took into account wind loads, all dead and live loads, and loads due to acceleration and deceleration. Allowable stresses due to combinations of these stresses were increased according to the Navy standard noted. A factor of safety of not less than five, based on the ultimate strength of the material and rated capacity of the crane, was used in the design of all mechanical parts.

62. 13.96- BY 22.45-FOOT FIXED-WHEEL GATES FOR PENSTOCK INTAKES. (a) *Description.*—Eight fixed-wheel gates are provided in the penstock intakes for emergency closure of the penstocks in case of damage to the penstocks or the powerplant equipment, and also to permit unwatering of the penstocks for inspection and maintenance. Normally, the gates will close only after flow through the penstocks has been stopped by closing the wicket gates. However, in an emergency the gate may be closed with water at full reservoir head flowing through the penstock. The gates were manufactured by Voest Co. of Linz/Donau, Austria, under invitation No. DS-5577. The frames were manufactured by Rockwell Engineering Co. of Blue Island, Ill., under invitation No. DS-5469. The general arrangement and some details of the 13.96- by 22.48-foot fixed-wheel gate installation are shown on figure 144.

Each gate is made in four units, fabricated from welded shapes and plate connected by rivets and rib bolts. Six wheels on each side of the gates carry the waterload to the tracks embedded in the downstream side of the gate slots. Rubber seals are mounted like a
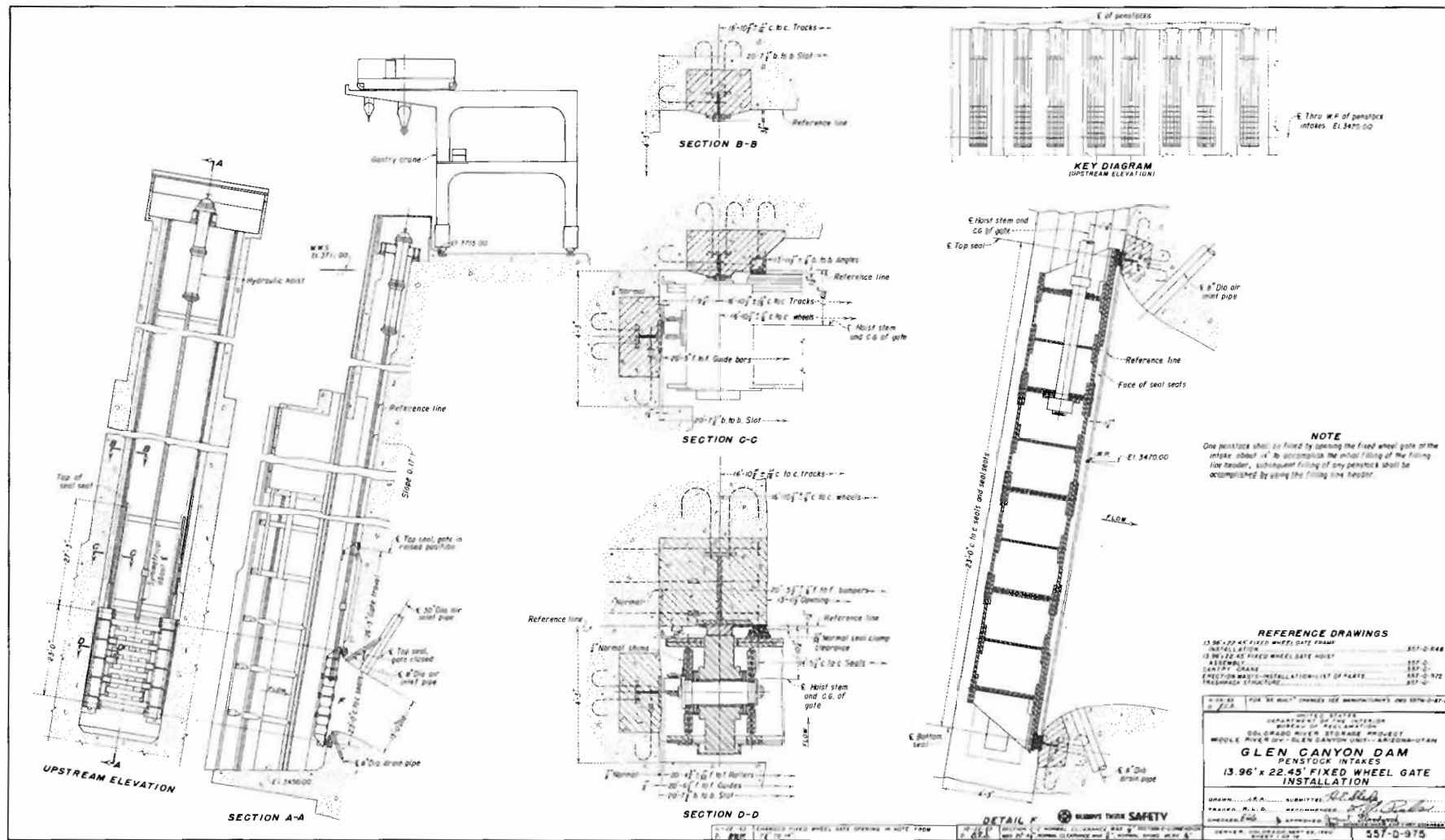
Figure 144.—13.96- by 22.45-foot fixed-wheel gate installation for penstock intakes.

picture frame on the downstream skinplate and bear against metal seats which surround the penstock intakes. Rollers at the sides of the gate provide lateral guidance for the gate and bear on embedded guides in the gate slot. A single hoist connection, located on the center of gravity, is provided. The gate travel is 26 feet 5 inches. The estimated weight of each gate is 231,000 pounds and of each frame is 70,000 pounds.

(b) *Design.*—Each gate was designed for a static head of 270 feet. The hoist connection at the gate was designed for the maximum hoist capacity.

Bending stresses in the horizontal and vertical beams were limited to 15,000 pounds per square inch tension and 14,000 pounds per square inch compression with the web shear limited to 9,500 pounds per square inch. Equivalent stress in the skinplate due to beam bending and skinplate bending was limited to 20,000 pounds per square inch. A portion of the skinplate was considered to be an integral part of the downstream beam flanges. The skinplate was also assumed to act as a haunched continuous beam with the supports on the centerline of the webs.

The stresses in the tracks and wheels were investigated by a method of calculating stresses due to the pressure of one elastic solid on another. The bushings in the wheels have self-lubricating inserts and may be greased when assembled. Friction forces of the loaded wheels, busings, seals, etc., were investigated to be certain that the gate would have sufficient weight to close without the aid of an externally applied force. Bearing pressure on the projected area of the bushing was limited to 4,000 pounds per square inch.

Figure 145 shows the downstream face of the gate as fabricated in the manufacturer's shop.

63. HOISTS AND CONTROLS FOR THE 13.96-BY 22.45-FOOT FIXED-WHEEL GATES. (a) *Description.*—A hydraulic hoist and control are provided to operate each of the eight 13.96- by 22.45-foot fixed-wheel gates. Normally, a hoist will be required to close the gate under balanced pressure to unwater the penstock for maintenance purposes, but may be required to close the gate under flow conditions in an emergency. Eight hydraulic hoists were furnished by the Pacific Coast Engineering Co., Alameda, Calif., under invitation No. DS-5601. The controls were manufactured by Auto-Control Laboratories, Inc., Los Angeles, Calif., under invitation No. (D) 90,638-A.

Figure 145.—Downstream elevation of shop assembly of 13.96-by 22.45-foot fixed-wheel penstock gate. P557-D-46362NA.

Some installation and assembly details are shown on figure 146. The hydraulic hoists are installed on the slope of the intake structure (0.170:1) at the upstream face of the dam and are supported by steel beams at elevation 3713.00. Each hoist is connected to the gate by a series of intermediate stems with an assembled length of 172 feet 9-3/4 inches. Each hoist piston has both packing and piston rings, is 30 inches in diameter, and has a stroke of 26 feet 5 inches. An individual control cabinet is located adjacent to each hoist in the control house, and contains all the hydraulic and electrical equipment for operating the hoist, and a gate position indicator.

The estimated weight of the eight complete hoists is 800,000 pounds and of the eight complete control systems is 42,000 pounds. Figures 147 and 148 show the shop assembly of the hoist and stems.

(b) *Design.*—The hoists were designed to open and close the gates normally with the water pressure balanced on both sides of the gates; to open any one of

Figure 146.—Installation of hoist for 13.96- by 22.45-foot fixed-wheel gate—Penstock intakes.
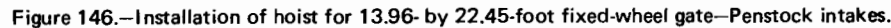
Figure 147.—Intermediate stems and coupling hooks for the 13.96- by 22.45-foot fixed-wheel gate. P557-D-37604.

the gates 14 inches for conduit filling with maximum unbalanced pressures on the gate; and in an emergency, to close the gates with full flow to the turbines under a maximum head of 255 feet. The cylinder size for the hoists was determined by the sum of the weights of the gate and stems, plus maximum downpull, minus friction of the coupling hooks sliding on the concrete guide surface, and minus one-half the gate wheel and seal friction. This load would produce a cylinder pressure of approximately 1,200 pounds per square inch during emergency closure; however, normal balanced operations or conduit filling will require a maximum cylinder pressure of less than 600 pounds per square inch. The hoists and stems were designed for a relief valve setting of 1,000 pounds per square inch, using normal factors of safety. The pressure switch setting of 750 pounds per square inch provides a minimum lifting force at the hoists of 437,000 pounds which exceeds the 392,000-pound force required to open the gate for conduit filling. The hoists were

designed to lower the gates, without operating the pumps, by bypassing oil from the underside of the piston directly to the top of the cylinder. The design time selected for opening the gates balanced was about 20 minutes, and for closing unbalanced less than 2 minutes, based on normal oil temperatures. The closing time will increase slightly as the oil temperature drops, and decrease slightly when the gate is subjected to downpull forces during emergency closure. A hanger stud is provided in the upper cylinder head of each hoist to engage the piston stem and support the weight of the stems and gate in the open position during gate installation or removal. During normal operation the hanger stud will not be engaged, as the piston was designed to support the gate and stems on oil confined under the piston.

Two constant-delivery pumps, having a combined delivery of 49 gallons per minute at a pressure of 1,000 pounds per square inch and a pump speed of 1,800
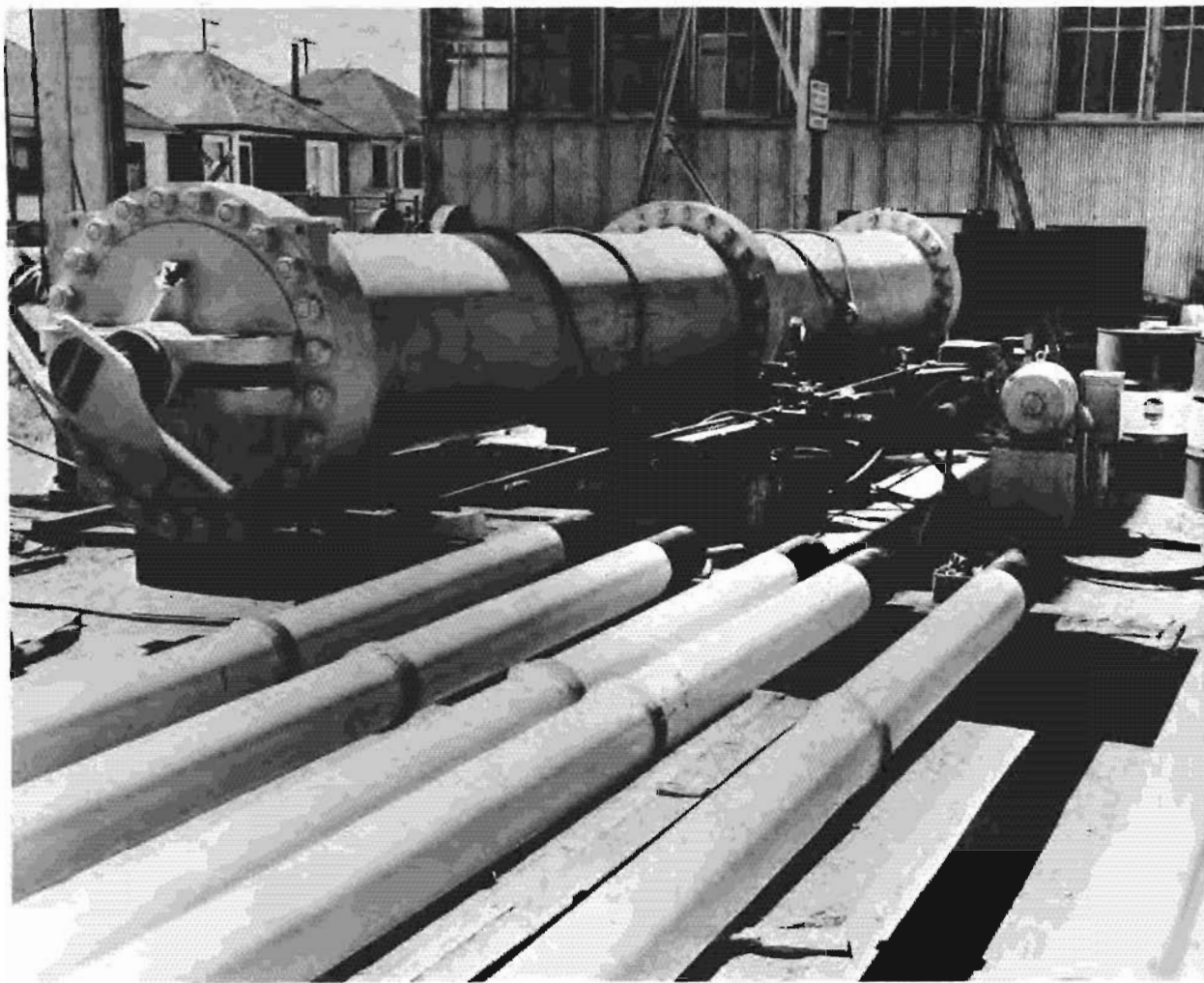
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Figure 148.--Hydraulic hoist and intermediate stems for the 13.96- by 22.45-foot fixed-wheel gate. P557-D-37603.

revolutions per minute were selected for each cabinet to open the gate within the predetermined design time. Two 15-horsepower motors, using 440-volt, 3-phase, 60-cycle current were required to drive the pumps. The two independent pump units were used to provide protection against failure of a single pump unit. A 110-volt transformer was used to provide power for most of the control circuits and the cabinet heater; however, the control was designed to use a separate source of direct-current power from the powerplant to operate the emergency close circuit and the solenoid-operated, four-way valve which directs the flow of oil to open, close, or stop the gate.

The control was designed for gravity closure of the gate with the closing speed controlled by a throttle valve in the bypass piping from the bottom to the top of the cylinder. A restoring cycle was incorporated in the controls to maintain the gate automatically within close limits of the open position. A penstock pressure switch was included to prevent opening the gate until the penstock is full and the pressures on either side of the gate are essentially balanced. Gate position indication was provided in the cabinet using a vertical scale with a pointer driven by a stainless steel cable connected to the piston stem.

The control was designed for normal gate operation by pushbutton from the control cabinet and for emergency gate closure by selector switch or automatic protective devices from the powerplant. The emergency close circuit was designed to override all opposing signals initiated from the control cabinet.
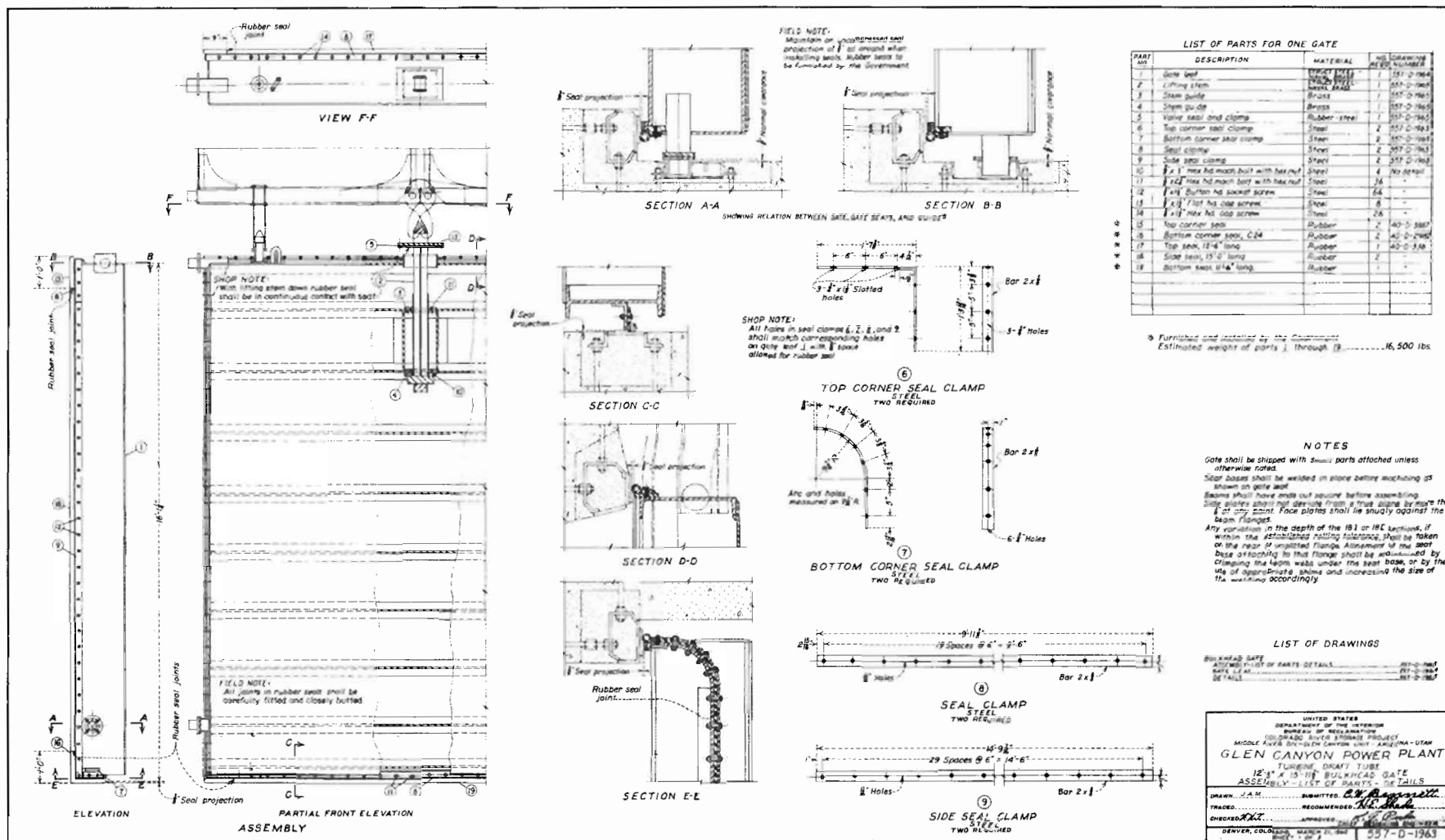
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Figure 149.—Turbine draft tube 12.42- by 15.95-foot bulkhead gate assembly.

The 214-gallon oil tank was selected to provide storage and expansion capacity for the hydraulic oil used in the system. The control design was based on a nominal temperature of 35° F. and the use of a lightweight hydraulic oil with a viscosity of 153 Saybolt seconds universal at 100° F. and a viscosity index of 97.

The design stresses used were as follows:

(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 stress 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 of the allowable design stresses in tension.

(4) *Structural steel.*—The 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 "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," 1961.

(5) *Hoist cylinders.*—The allowable design stresses for the hoist cylinders were based on the recommendations of the ASME Boiler and Pressure Vessel Code—Unfired Pressure Vessels—Section VIII, 1962.

64. TURBINE DRAFT TUBE BULKHEAD GATES. (a) *Description.*—Twenty-four bulkhead are provided to seal the turbine draft tubes from the tailwater in the event that it is necessary to unwater the turbine units for inspection and maintenance of either equipment or structure. The 24 bulkhead gates and related equipment (fig. 149) were furnished under invitation No. DS-5341.

A gate having nominal dimensions of 12.42 feet wide by 15.95 feet high is available for each of the draft tube openings. The gates and lifting frame operate in steel guides embedded vertically in the concrete structure. The gates are raised and lowered by means of a 10-ton gantry crane. An automatically engaging lifting frame is used for raising and lowering the gates.

The gates are normally stored in the upper portion of the gate slots. The gates are supported by latches so located that the lifting lug on the gate is just below the deck slot covers and is therefore easily accessible from the deck. The latches consist of hinged bars which will automatically engage the gate guide lugs during the raising cycle, and may be laid back out of the path of the gate guide lugs to allow the gate to lower.

Inasmuch as the gates must be raised and lowered only under balanced head conditions, a filling valve is incorporated in the gate lifting stem of each gate for the purpose of creating the balanced head prior to raising the gates. In the event that high-pressure penstock water is unintentionally admitted to the turbine and draft tube while the gates are in place, a gate will blow off of its seat, shearing the bolts which fasten the lower guide lugs to each side of the gate. The top guide lugs are rigidly fixed to the gate, enabling the gate to swing out in the event that the lower guide lugs shear. The estimated weight of the 24 gates is 396,000 pounds.

(b) *Design.*—Maximum stresses are calculated on the basis of a dry draft tube and maximum tailwater surface, the maximum head being 78 feet. Under these conditions the combined stresses of the faceplate and beams are permitted to reach 24,000 pounds per square inch. Other stresses conform to the American Institute of Steel Construction.