# CHAPTER V. *Design—SPILLWAY*

**40. GENERAL.** One spillway is provided on each abutment. Each spillway consists of an approach channel, intake structure, spillway tunnel, and deflector bucket. Spillway discharges are controlled by two 40- by 52.5-foot radial gates in each intake structure. General plans and profiles of the spillways are shown on figures 100 and 101.

**41. HYDRAULICS.** To determine required spillway capacity, two inflow floods were considered:

(1) A maximum probable snowflood which had a peak inflow of 380,000 cubic feet per second and a 122-day volume of 29,060,000 acre-feet.

(2) A maximum probable rainflood which had a peak inflow of 417,000 cubic feet per second and a 6-day volume of 2,063,000 acre-feet.

Studies indicated the snowflood to be the critical flood and it was therefore adopted as the inflow design flood.

The design flood was routed through the reservoir, assuming that the reservoir was at elevation 3700, top of conservation storage, at the beginning of the flood. The maximum reservoir water surface obtained from the routing was elevation 3711 and the maximum outflow was 300,000 cubic feet per second. The spillways were sized to have a combined capacity of 276,000 cubic feet per second with the reservoir at elevation 3711. The remaining 24,000 cubic feet per second would be released through the river outlets and turbines.

The locations of the spillways were set to provide a satisfactory alinement with the river. This resulted in the intake structures being located well back of the canyon rim. Intake channels were provided for flow from the reservoir at the canyon rim to the intake structures.

The intake structures were designed to control releases and provide an entrance to the tunnels. The concrete crest is at elevation 3648.00. Two 40- by 52.5-foot radial gates are installed at the crest of each intake structure to control releases. Discharge curves for the radial gates are shown on figure 102. The crest shape is designed to follow the under nappe for a gate opening of 10 feet. The coefficient of discharge for the uncontrolled crest with maximum reservoir water surface is 3.46. The crest and gates are set at a converging angle of 84° from the centerline of the

tunnel to start the transition and to decrease the tunnel portal width.

The spillway tunnels for the greater part of their length are 41 feet in diameter. The transition section downstream from the intake structure changes from a flat-arch-roof section 89 feet wide by 52 feet high to a circular section 48 feet 3 inches in diameter. From this point there is a further transition of the circular section to the 41-foot-diameter tunnel. The tunnels were designed to flow partially full, and at all sections the depth of the water will be 0.7 times the height of tunnel, or less.

At the downstream portals a concrete deflector bucket was designed to lift the jet of water a safe distance into the center of the river channel and also to deflect the jet away from the canyon wall.

**42. MODEL STUDIES.** The original layout for the spillway tunnels was based on data obtained from other tunnel spillways built by the Bureau, routing of the flood through the tunnels, and adapting the lower ends of the tunnels to the diversion scheme.

Extensive hydraulic model studies of both spillway tunnels were made on a 1:63.48 scale model.[1] These studies aided in determining the final dimensions of the approach channel, the transition section of the tunnel, and the location and final shape of the deflector buckets. Model studies indicated that the maximum velocity in the spillway tunnel will be 162 feet per second. Discharge curves shown on figure 102 were determined by the model studies.

**43. CONCLUSIONS FROM MODEL STUDIES.** In addition to the maximum spillway tunnel velocity stated above, other conclusions from the model studies are:

(1) The alinement of the tunnels was satisfactory for diversion flows and spillway flows.

(2) Preliminary tests on a 1 to 88 scale model indicated that the most satisfactory invert angle for the flip buckets was 35°. Subsequent tests on the 1 to 63.48 spillway model confirmed this.

(3) A low curved concrete wall placed adjacent to each canyon wall protected the canyon walls from further undermining and erosion damage by diversion flows.

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[1] "Hydraulic Model Studies of the Spillways and Outlet Works—Glen Canyon Dam," Hydraulic Laboratory Report No. Hyd-469, Bureau of Reclamation, February 18, 1964 (unpublished).
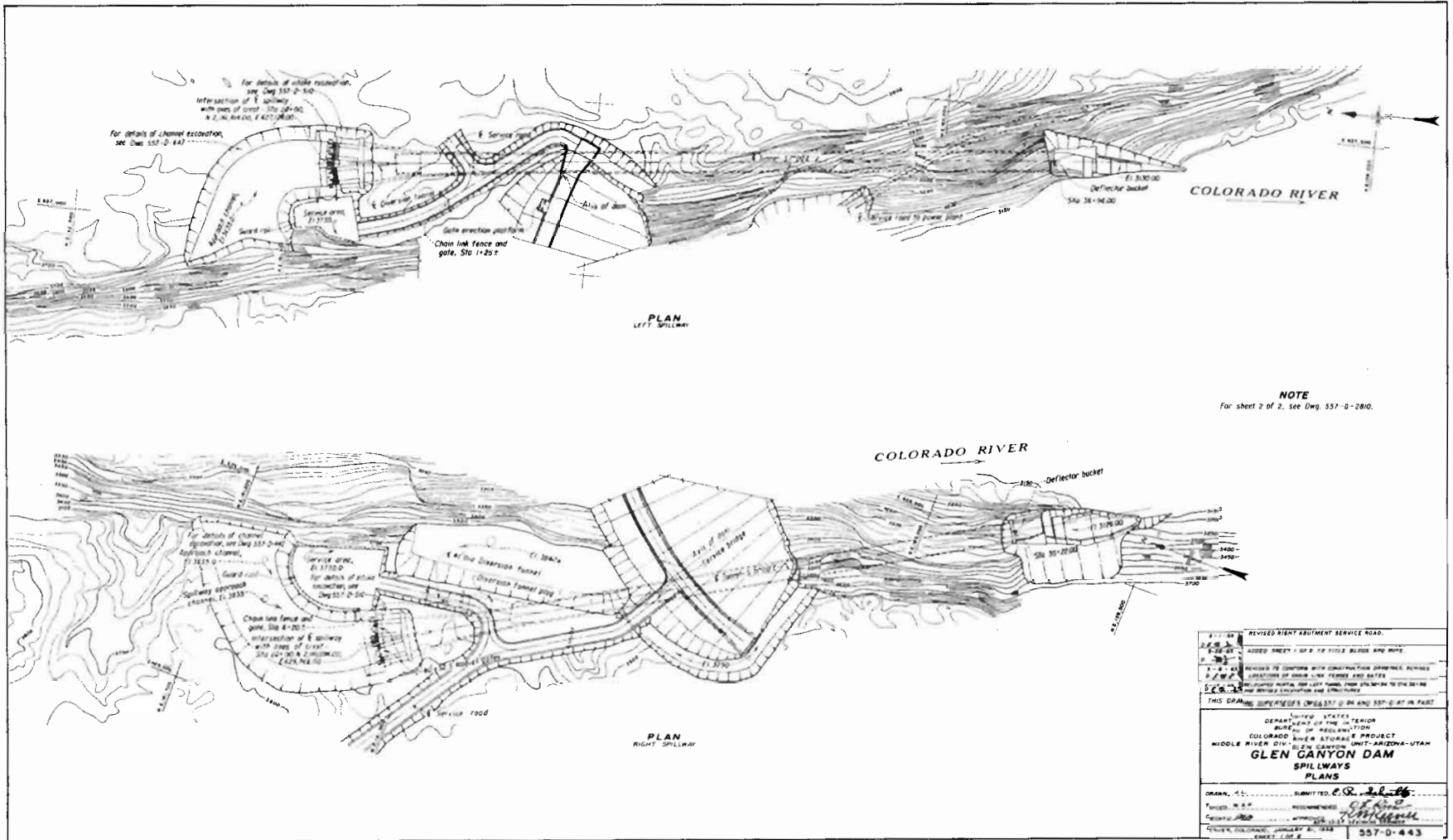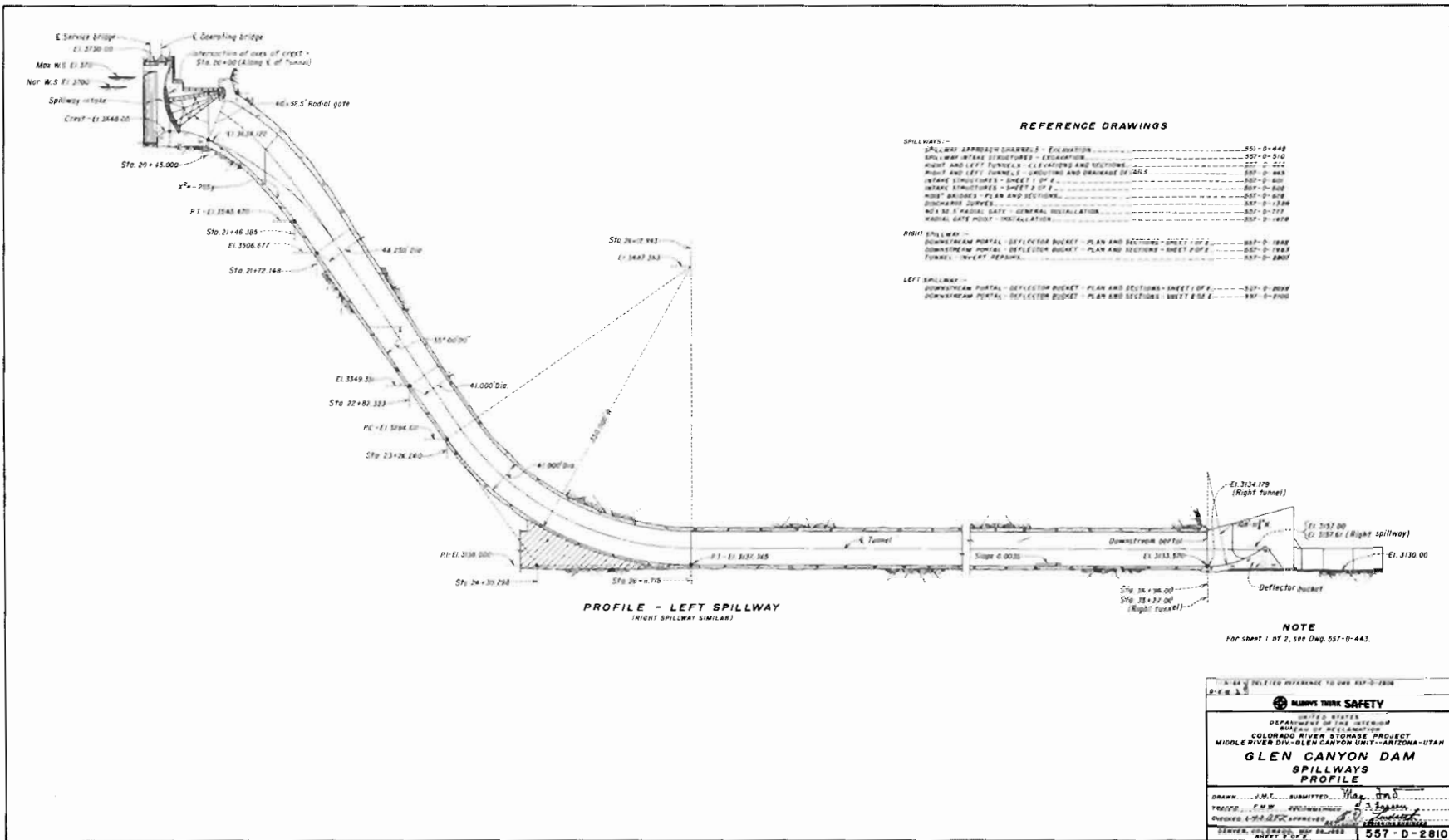
Figure 100.—Dam spillways—Plans.
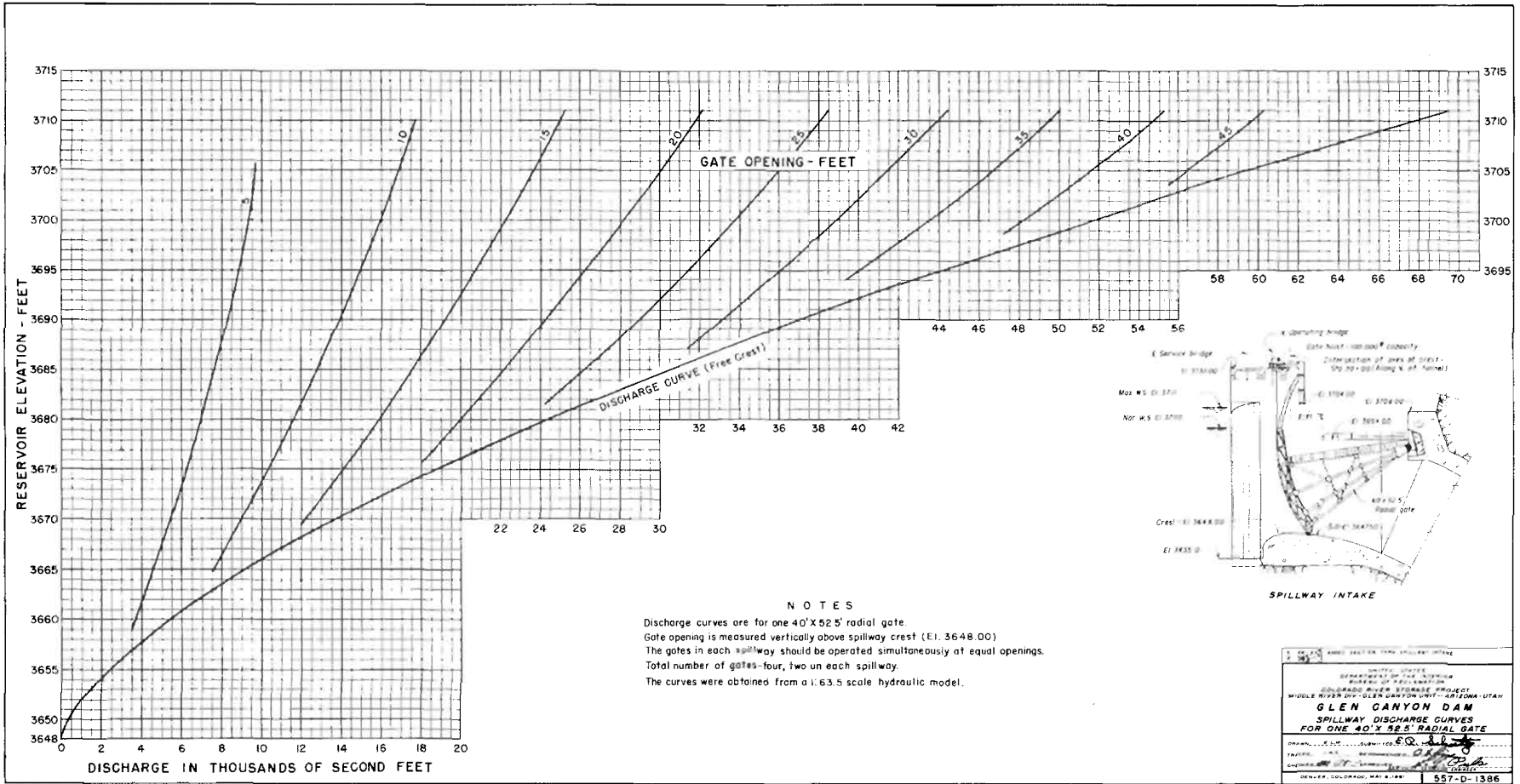
Figure 101.—Dam spillways—Profile.

Figure 102.—Spillway discharge curves for one 40- by 52.5-foot radial gate.

(4) The spillway approach channels were greatly reduced from their original size and still provided extremely smooth flow conditions.

(5) Flow through the crest sections was excellent and no adverse pressure conditions were noticed. The maximum discharge of 138,000 cubic feet per second per tunnel was obtained at reservoir elevation 3711, the value used for design purposes.

(6) The preliminary tunnel transition was too abrupt. A surface fin formed in the center of the tunnel and pressures on the sidewalls were in the cavitation range.

(7) The longer recommended transition (fig. 104) was adequately streamlined and provided smooth flow conditions with no adverse pressures on the sidewalls.

(8) Flow in the 41-foot-diameter tunnels was excellent at all discharges.

(9) The preliminary downstream circular-to-rectangular tunnel transition was too short, as indicated by severely subatmospheric pressures in the lower corners. Increasing the transition length from 70 to 100 feet increased the pressures to a satisfactory value. This transition was eliminated in the recommended design.

(10) The preliminary deflector buckets, which were rectangular in cross section, were replaced by a bucket in which the circular invert of the tunnel intersected the vertical curve of the bucket. This type of bucket also eliminated the need for the circular-to-rectangular transition.

(11) The deflector buckets were moved upstream to the tunnel portals, eliminating about 200 feet of open channel.

(12) The outside walls of the buckets were turned inward 7 feet to direct the flow in a more favorable pattern at their impact points.

(13) The outside wall of the left bucket was extended 32.5 feet downstream from the lip to deflect the flow from the canyon wall.

(14) Pressure measurements on the wall and invert of the left bucket showed that pressures equivalent to 211 feet of water would be considered in the structural design of the bucket.

44. STRUCTURAL DESIGN. (a) *Intake Structure.*—The layout of the intake structure is shown on figure 103. The design was based on concrete having a compressive strength of 3,000 pounds per square inch at 28 days. The allowable working stresses, except as noted below, are shown on figure 71.

The crest and piers were designed for earthquake, hydrostatic pressure, uplift, and service bridge loadings. Earthquake loadings of 0.1 g horizontally and 0.05 g vertically were used. The horizontal component of thrust from the radial gates is carried directly to the rock through a massive beam above the portals of the tunnels. This beam was designed to support the vertical component of the thrust as well as the reaction of the weight of the gate and trunnion assemblies. The bridge was designed for the load imposed by the gate hoists and for a 20-ton truck-mounted crane.

The period of vibration of the center pier was found to be in the earthquake resonance zone and, therefore, this pier was designed for 0.7 g earthquake; however, the allowable stresses in the reinforcement were increased to 40,000 pounds per square inch for this condition. A split sewer-pipe drainage system was placed in the walls and on the foundation of the crest structure for uplift pressure relief.

(b) *Tunnel.*—The arrangement of each tunnel and transition is shown on figure 104.

The thickness of the tunnel lining for the circular sections was made 0.8 inch per foot of the tunnel diameter. The lining was reinforced where required for tension caused by the dam and reservoir waterloads. The stresses in the vicinity of the tunnels were determined by Newmark's method of computation of stresses in elastic foundations. Stresses in the lining caused by the stresses in the rock were determined by both analytical and model studies.[2]

Moments, thrusts, and shears in the noncircular transition section of the tunnels were determined by photoelastic model studies[3] of various sections for hydrostatic load, dead load, grout load, and rock load based on the assumption that the height of the rock acting on the structures was equal to 0.35 of the excavated width. A grout load of 3,600 pounds per square foot over a 90° sector of the arched roof, or between spring lines, whichever was least, were used for design. The results of these studies were used to determine final concrete thickness and reinforcement.

[2] Interoffice Memorandum to Chief, General Engineering Branch, from H. Boyd Phillips and Ira E. Allen, "Electrical Analogy Tray Study of Pressures on Spillway Tunnel Lining, Glen Canyon Dam," October 29, 1956 (unpublished).

[3] Interoffice Memorandum to Chief, Dams Branch, from H. Boyd Phillips and Ira E. Allen, "Stress Analysis of Transition Section, Spillway Tunnel—Glen Canyon Dam," November 19, 1957 (unpublished).
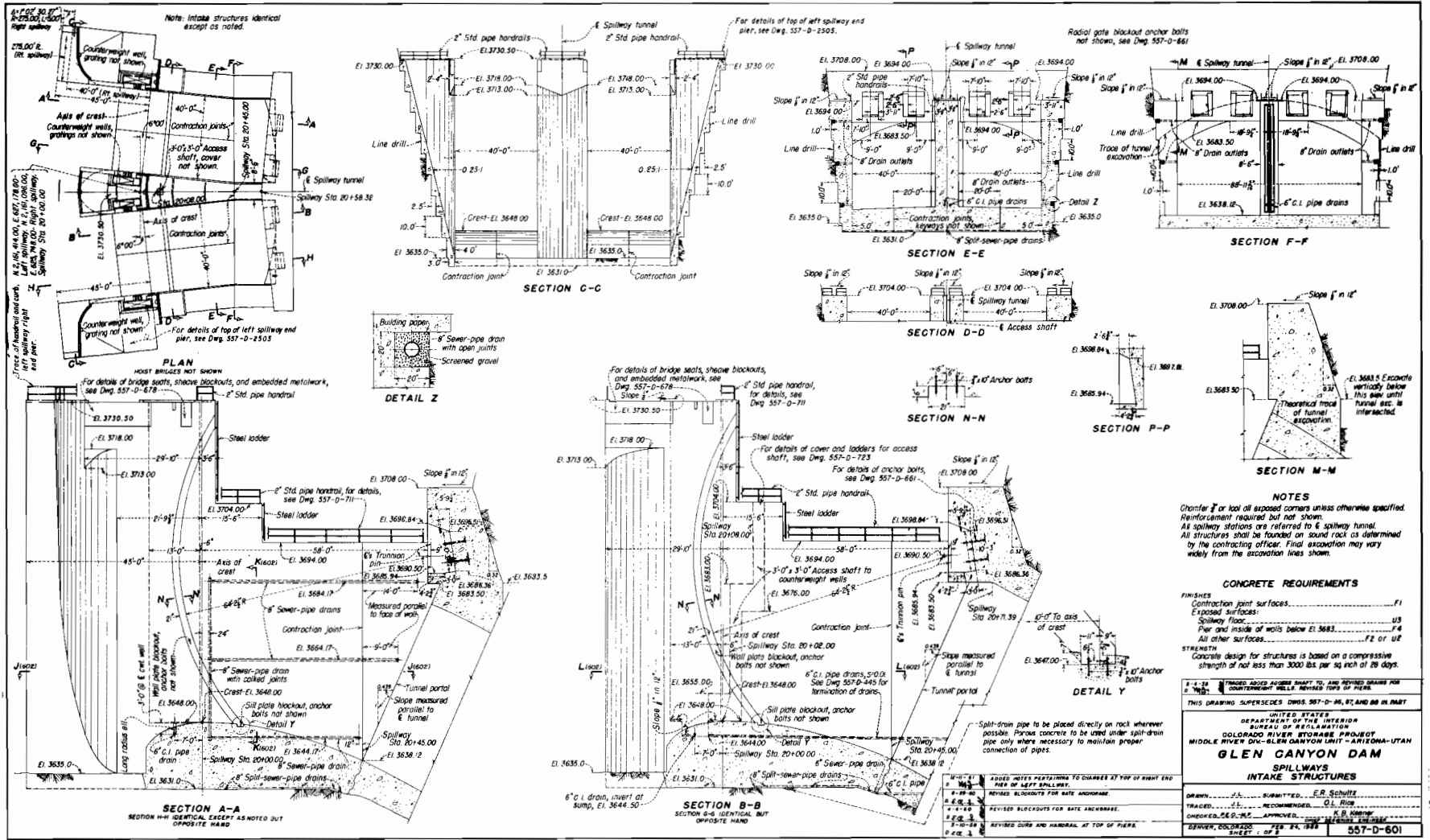
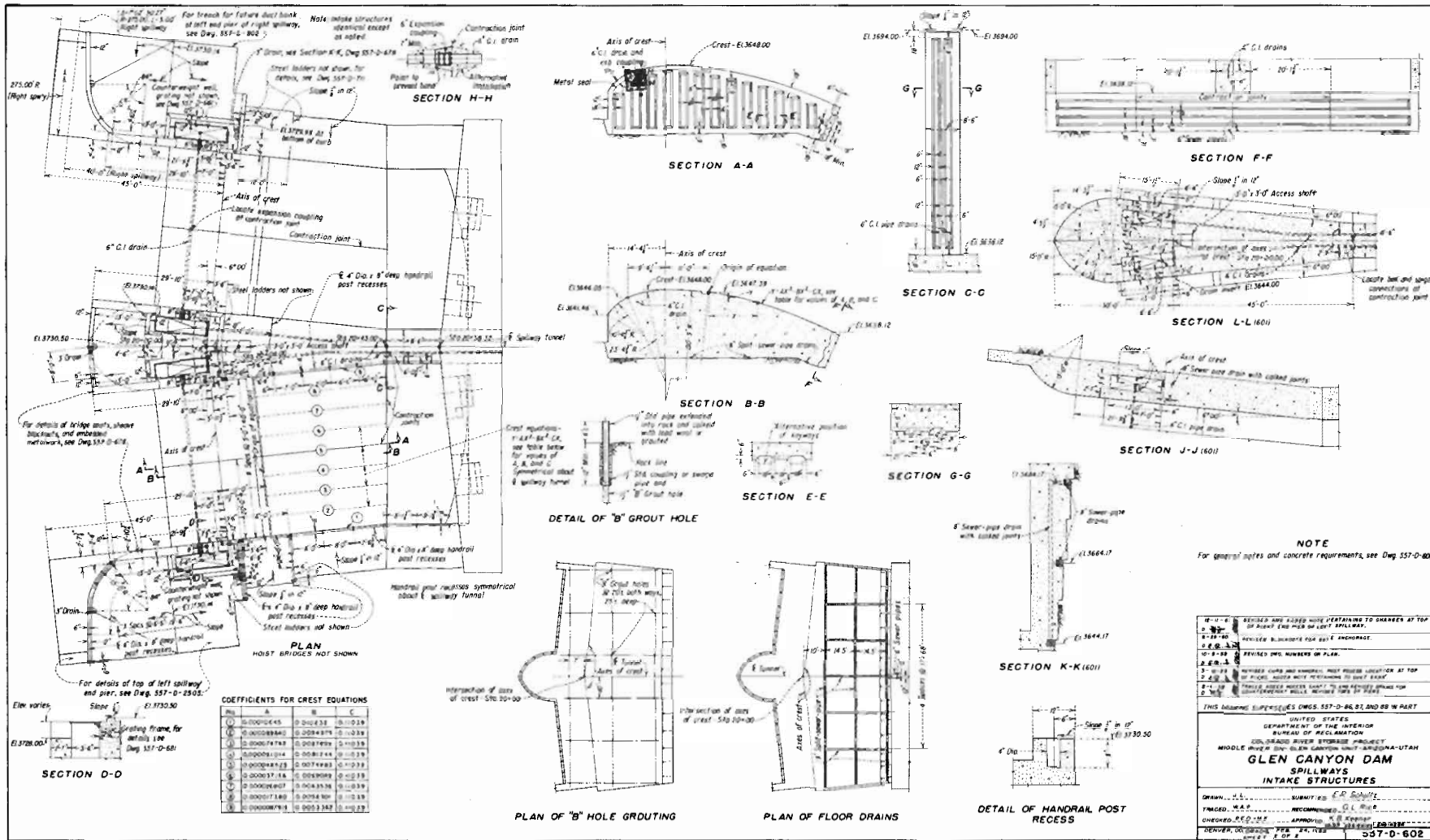Figure 103.—Spillways intake structures. (Sheet 1 of 2.)

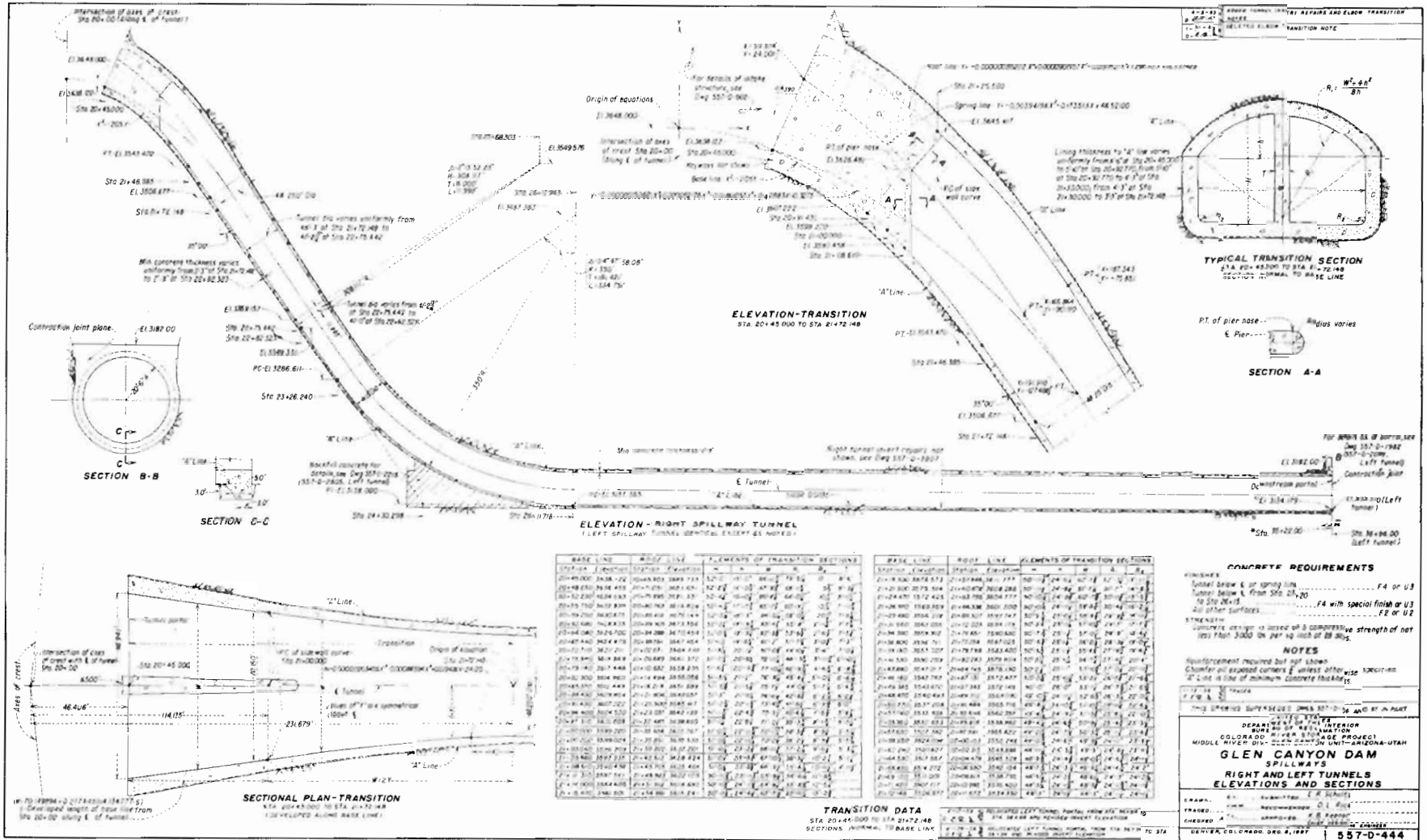Figure 103.—Spillways intake structures. (Sheet 2 of 2.)

Figure 104.—Spillways, right and left tunnels—Elevations and sections.

The rock surrounding the tunnels upstream from the downstream end of the elbow and at the downstream portal was grouted from radial holes ranging from 20 to 40 feet in depth, spaced at up to 20-foot centers measured along the centerline of the tunnels. Drainage holes 3 inches in diameter, drilled radially 25 feet deep at 20-foot centers, were also provided in the tunnels from the entrances to a point 400 feet downstream from the elbows. Grouting and drainage details are shown on figure 105.

The inverts of the horizontal portions of both tunnels were eroded during diversion. Repairs were made with epoxy-bonded concrete and epoxy-bonded epoxy mortar to insure the serviceability of the tunnels.

(c) *Deflector Bucket.*—The layout of the left spillway deflector bucket is shown on figure 106. The layout for the right deflector bucket is similar but opposite hand.

The reinforced concrete deflector buckets were designed for dead weight, static and dynamic forces from water at maximum discharge, and uplift pressure. In general, the bucket was designed as a monolithic structure resting on an elastic foundation. The dynamic forces from the deflecting jet were determined from the hydraulic models.[1]

Seams and joints were observed in the rock at the outlet portal of the left tunnel. To prevent the rock from slabbing off, 1-1/2-inch-diameter post-tensioned anchors 20 feet long were installed as shown on figure 22. These were tensioned by applying a torque of between 450 and 550 foot-pounds.

45. 40- BY 52.5-FOOT RADIAL GATES. (a) *Description.*—Four radial gates are installed in the spillway intake structures and are used to regulate discharges into the spillway tunnels. The gates were manufactured by Vereinigte Osterreichische Eisen und Stahlwerke (VOEST), Linz-Donau, Austria under invitation No. DS-5192. The embedded metalwork for the gates was manufactured by Dixie Steel and Supply Company, Inc., Tuscaloosa, Ala., under invitation No. DS-5077.

The radial gates are located near the crest of the spillway intake structures, upstream from the right and left abutments of the dam. The general installation is shown on figure 107. Each gate is operated by a wire-rope drum hoist on the operating bridge with movable counterweights in the pier and end wall of the spillway.

The estimated weight of the movable parts of each gate is 326,000 pounds, and the estimated weight of the nonmovable parts is 64,000 pounds. Figure 108 shows the shop assembly of one gate.

(b) *Design.*—The gate was designed for a head of 52.5 feet for two conditions; namely, (1) water surface at top of gate, elevation 3700.0 (gate closed), and (2) water surface at top of gate, elevation 3715.0 (gate partially raised). The hydraulic force on the skinplate and vertical stiffeners is transmitted to the four horizontal girders. The load from the girders is carried to the arms and trunnion pins which are located at the center of curvature of the skinplate. The load from the trunnion pins is carried to the pedestals which are attached to base castings embedded in the concrete headwall of the spillway tunnel. The pedestals were alined and held in place by bolts and jacks before making the final placement of concrete in the headwall blockouts. The trunnion pin bushing is provided with seals to prevent entry of foreign matter.

Grease fittings are provided for lubrication of the bushing. Lateral movement of the gate is controlled by four guide shoes on each side.

The rubber side seals are provided with brass bars to reduce the sliding friction. The flat bar rubber bottom seal extends below the lower edge of the skinplate and is compressed to prevent leakage when the gate is seated.

Two sets of hoist wire ropes and two counterweight ropes are connected to the lifting brackets on the skinplate. Part of the lifted load is carried to the hoist and the remainder to the counterweights in the pier and end wall. The maximum load on the ropes is 262,000 pounds.

The design was based on the following unit stresses expressed in pounds per square inch:

Combined longitudinal and trans-
    verse stresses in skinplate . . . . . . . . . . 20,000
Tension
    Net sectional of rolled members . . . . . . . 18,000
    Upset anchor bolts . . . . . . . . . . . . . 15,000
Bending
    Compression in girders and
        rolled members . . . . . . . . . . . . . 18,000
    Trunnion pins . . . . . . . . . . . . . . . . 16,000
Shear
    Webs of girders and rolled
        members . . . . . . . . . . . . . . . . . 12,000
    Rivets . . . . . . . . . . . . . . . . . . . . 13,500
    Ribbed bolts . . . . . . . . . . . . . . . . 15,000

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[1] Op. cit. p. 145.
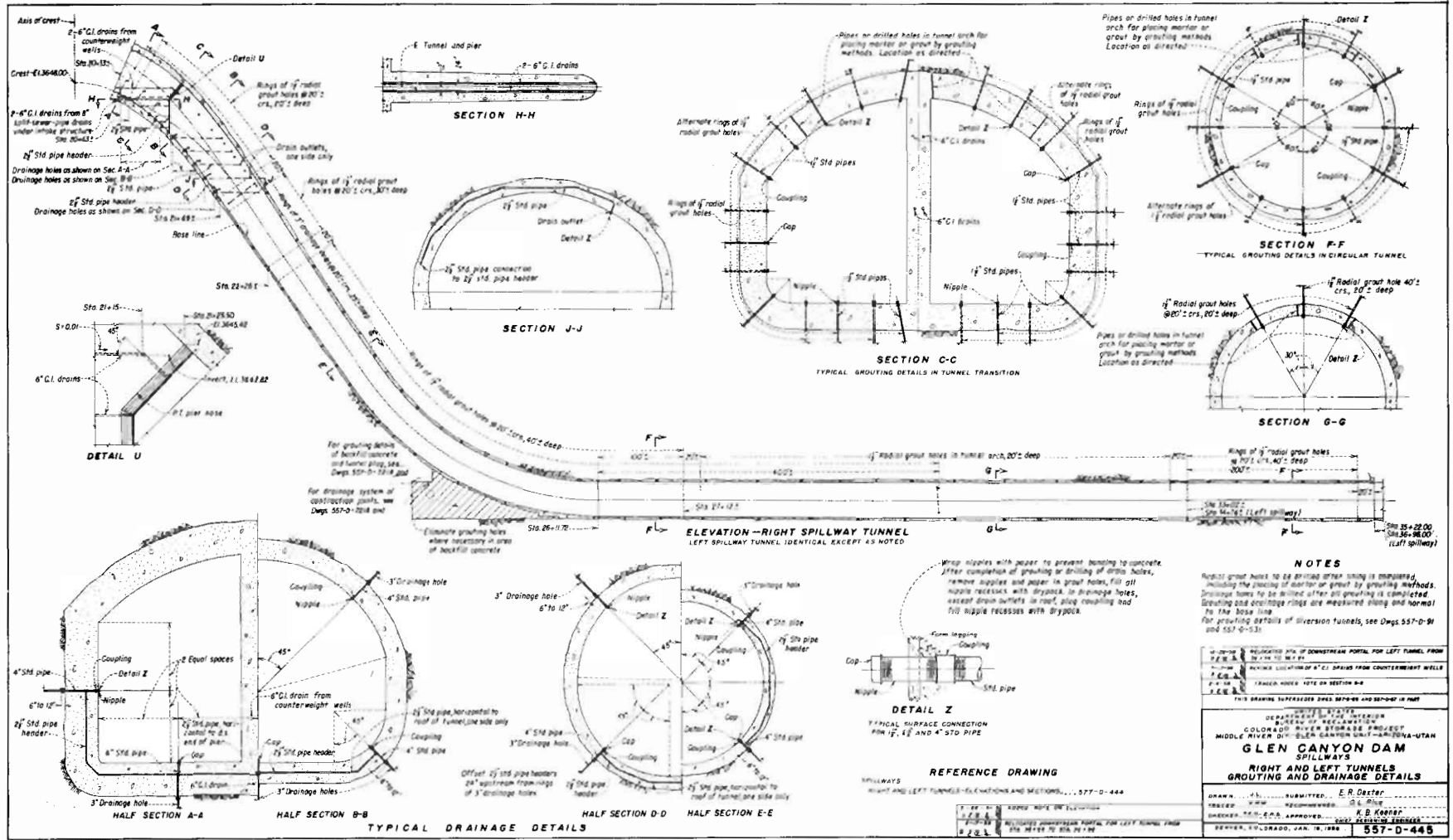
Figure 105.—Spillways, right and left tunnels—Grouting and drainage details.

Figure 106.—Left spillway downstream portal deflector bucket—Plan and sections. (Sheet 1 of 2.)

DETAIL Z (2099)

SECTION J-J

SECTION G-G (2099)

SECTION D-D (2099)
TYPICAL FROM STA. 56+96 TO STA. 57+28

SECTION E-E (2099)
TYPICAL FROM STA. 57+28 TO STA. 57+41.96

SECTION F-F (2099)
TYPICAL FROM STA. 57+41.96 TO STA. 57+68

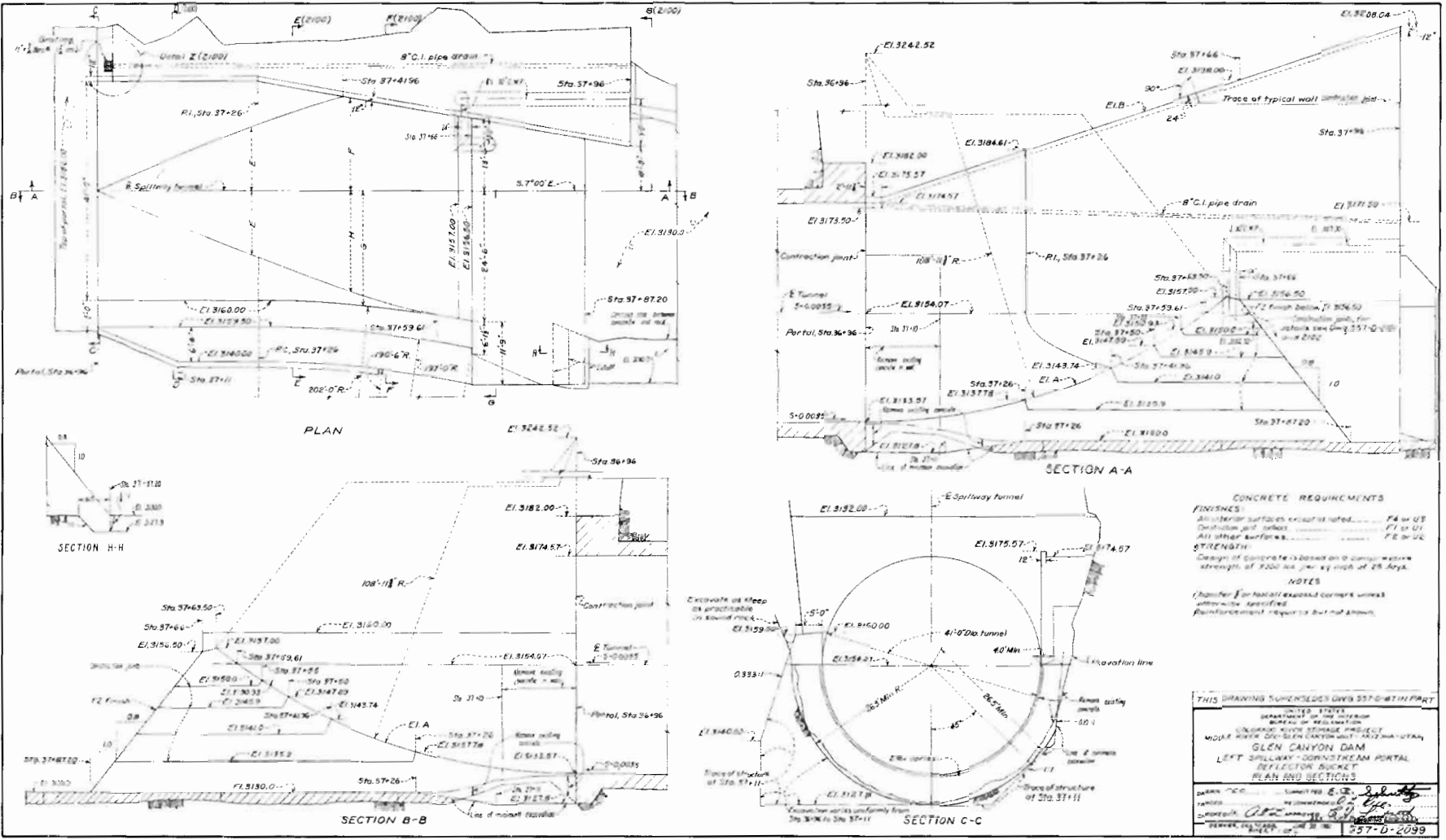TRANSITION DATA

NOTE
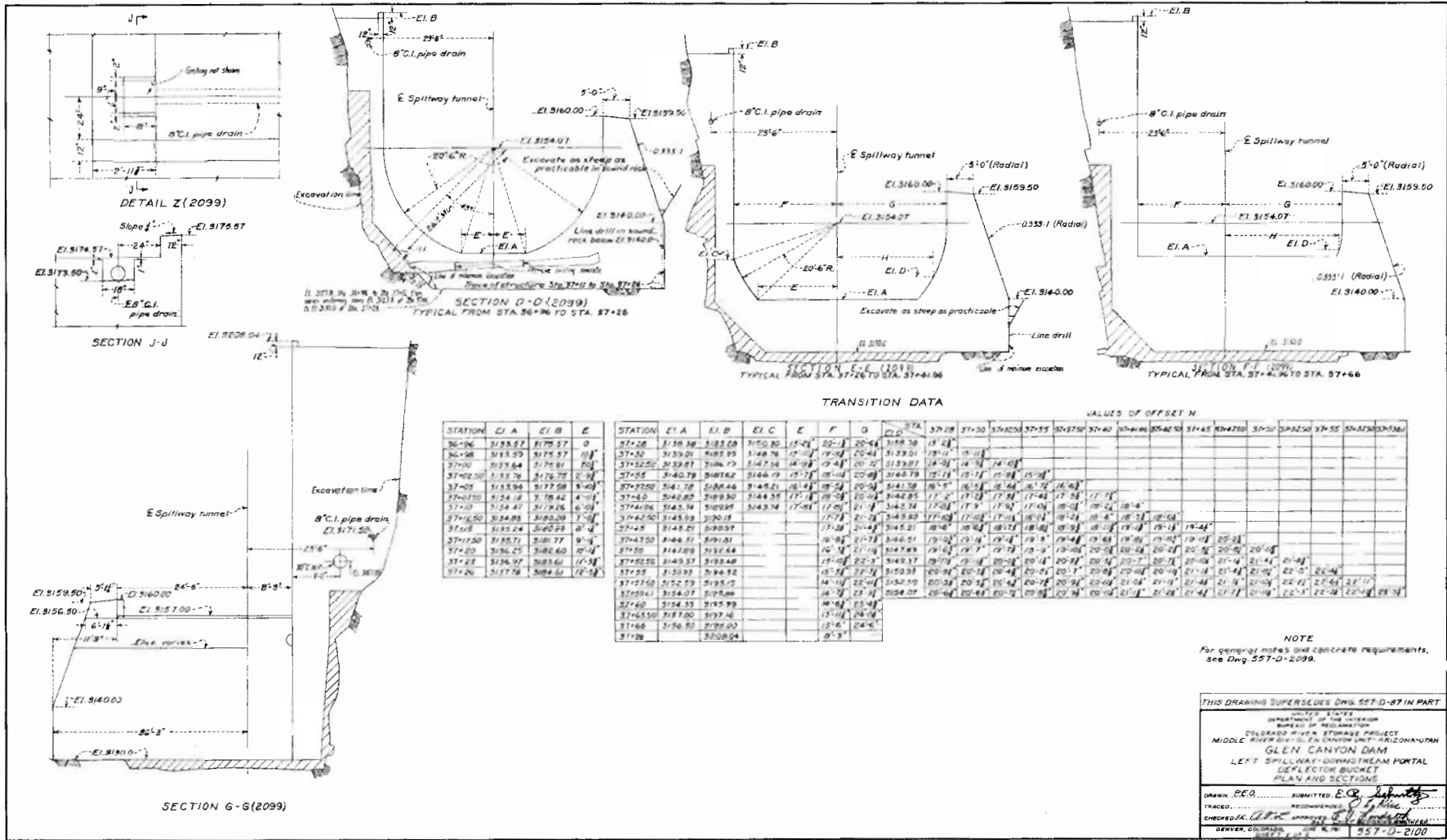For general notes and concrete requirements,
see Dwg. 557-D-2099.

Figure 106.—Left spillway downstream portal deflector bucket—Plan and sections. (Sheet 2 of 2.)
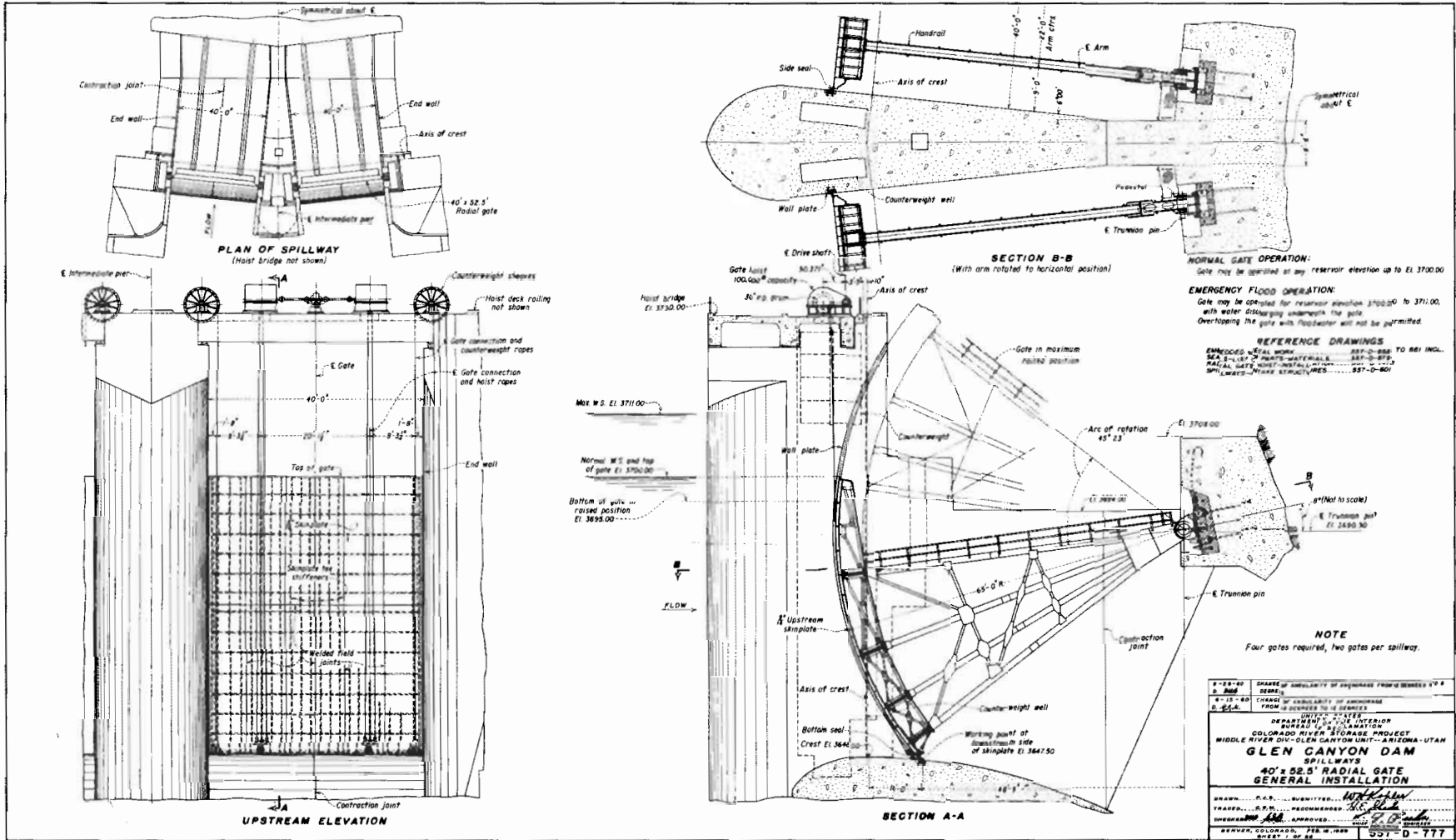
Figure 107.—Dam spillways, 40- by 52.5-foot radial gate—General installation.
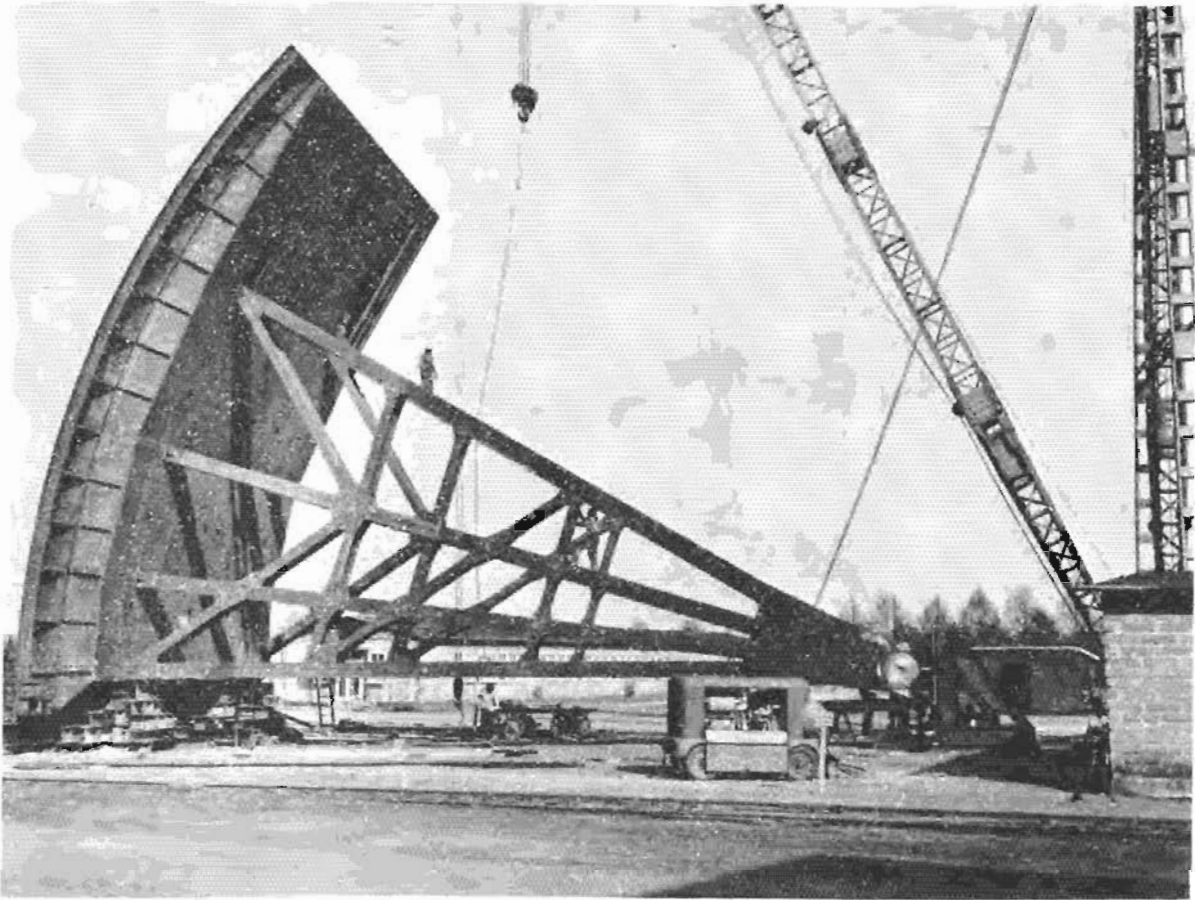
Figure 108.—40- by 52.5-foot radial gate for spillway—Side elevation of shop assembly. TPX-D-21976.

Bearing

   Rivets and ribbed bolts, single
      shear . . . . . . . . . . . . . . . . . . . 24,000

   Rivets and ribbed bolts, double
      shear . . . . . . . . . . . . . . . . . . . 30,000

   Trunnion pins . . . . . . . . . . . . . . . . 20,000

   Bronze bushings, projected area . . . . . . . 3,500

Compression

   Arm columns, maximum $\frac{l}{r} = 61$ . . . . . . . 14,910

Assumed coefficient of side seal
   friction, brass on stainless steel . . . . . . F = 0.25

Assumed coefficient of trunnion
   pin friction, bronze or steel . . . . . . . . F = 0.10

46. SPILLWAY RADIAL GATE HOISTS (a) Description. — Two 100,000-pound-capacity radial gate hoists are installed on the operating deck of each spillway for raising and lowering the radial gates. The gates were furnished under invitation No. DS-5213.

Each hoist consists of a center-drive unit and two drum units. The drum units are mounted on the hoist deck directly above the gate rope connections. The center-drive unit is mounted on the hoist deck on the centerline of the gate. There are two concrete counterweights, each weighing approximately 80,000 pounds, connected to each gate to reduce the lifting effort required of the hoist. A single 2-1/4-inch-diameter 6 by 37 stainless steel wire rope with independant wire-rope core is reeved over a 6-foot-diameter sheave connecting each counterweight to the gate. The counterweights are located in wells in the piers adjacent to each gate.

The center-drive unit consists of a 10-horsepower, 350-r.p.m., gear motor with a motor-mounted, electrical-release, disk-type brake and a commercial 50 to 1 worm gear reducer with a double extended output shaft. A floating shaft and two flexible couplings connect the center unit to each drum unit.

Each drum unit consists of two stages of spur reduction gearing and a 30-inch pitch-diameter drum. The drum is grooved right and left hand for 2 parts of 1-1/2-inch-diameter 6 by 37 stainless steel wire rope with independant wire-rope core. The ropes extend from the drum and are attached to an equalizer bar located on the upstream side of the gate.

The drum unit base is of welded steel construction. Antifriction roller bearing pillow blocks support the drum and spur gear shafts. A double-acting, screw-type, snap action limit switch is installed on one drum unit of each hoist to limit the travel in both the hoisting and lower directions.

Each counterweight consists of four reinforced concrete blocks suspended on a steel hanger. The bottom block of each counterweight is provided with a steel lifting bar at each end to permit assembly of all four blocks onto the hanger. Guide wheels are mounted on top of each counterweight to prevent rotation and binding in the wells due to the twist of the wire rope. The counterweight sheaves are bronze bushed and are designed to rotate on the sheave shaft. Each sheave and shaft is supported by two welded steel pedestals mounted on the piers.

(b) *Design.*—The hoists were designed with a safety factor of 5 based on the ultimate strength of the material and assuming 60 percent of the total rated torque applied on one end unit. Also, each part was designed so that the stress will not exceed 80 percent of the yield point of the material, based on the breakdown torque of the motor and 50 percent of the torque applied at each end unit. The hoist ropes were designed with a factor of safety of 5.5 and the counterweight ropes with a factor of safety of 4.4 on the breaking strength of the ropes.

Electric motor control equipment is discussed in section 39.