CHAPTER 3

SPILLWAYS, OUTLET WORKS AND APPURTENANCES, AND RESTITUTION CONCRETE

3-1. Introduction. This chapter describes the influence of voids through the arch dam and structural additions outside the theoretical limits of the arch dam. Voids through the dam in the radial direction are spillways, access adits, and outlet works, in the tangential direction are adits, galleries, and tunnels, and in the vertical direction are stairway wells and elevator shafts. Often associated with spillways and outlet works are blockouts or chambers for gate structures. External structures are restitution concrete which includes thrust blocks, pads, pulvino, socle, or other dental type concrete, spillway flip buckets on the downstream face, and corbels on the upstream face.

3-2. Spillways. Numerous types of spillways are associated with arch dams. Each is a function of the project purpose, i.e., storage or detention, or to bypass flood flows or flows that exceed diversion needs. Spillways for concrete dams may be considered attached or detached.

a. Attached Spillways. Attached spillways are through the crest or through the dam. Through-the-crest spillways have a free fall which is controlled or uncontrolled; OG (ogee) types are shaped to optimize the nappe. In general, the usual crest spillway will be constructed as a notch at the crest. The spillway notch can be located either over the streambed or along one or both abutments as shown in Figure 3-1. A spillway opening can also be placed below the crest through the dam. Similar to the notch spillway, this opening can be located either over the streambed, as shown in Figure 3-2, or near one or both abutments. The location through the dam, whether at the crest or below the crest, is always a compromise between hydraulic, geotechnical, and structural considerations. Impact of the jets on the foundation rock may require treatment to avoid eroding the foundation. Spillways through the dam are located sufficiently below the crest so that effective arch action exists above and below the spillway openings.

(1) Spillway at Crest. With this alignment, the spillway crest, piers, and flipbucket are designed to align the flow with the streambed to cause minimal possible bank erosion and/or to require minimal subsequent beneficiation. However, the notch reduces the arch action by the depth of the notch, i.e., the vertical distance between the dam crest and spillway crest which is normally pure arch restraint is nullified and replaced with cantilever action. To accommodate this reduced stiffness, additional concrete must be added below the spillway crest or the entire arch dam must be reshaped, thus complicating the geometry. Not that this is detrimental, but arch dam shapes work more efficiently when kept simple and smooth in both plan and elevation. Moving the spillway notch to either abutment as shown in Figure 3-1 or splitting the spillway crest length and locating half along each abutment will restore most of the arch action to the dam crest. Spillway notches through the crest near abutments interrupt arch action locally, but not significantly, as can be shown in numerous numerical analysis and scale model studies. The effect of abutment spillways is structurally less distressful on arch dams in wide

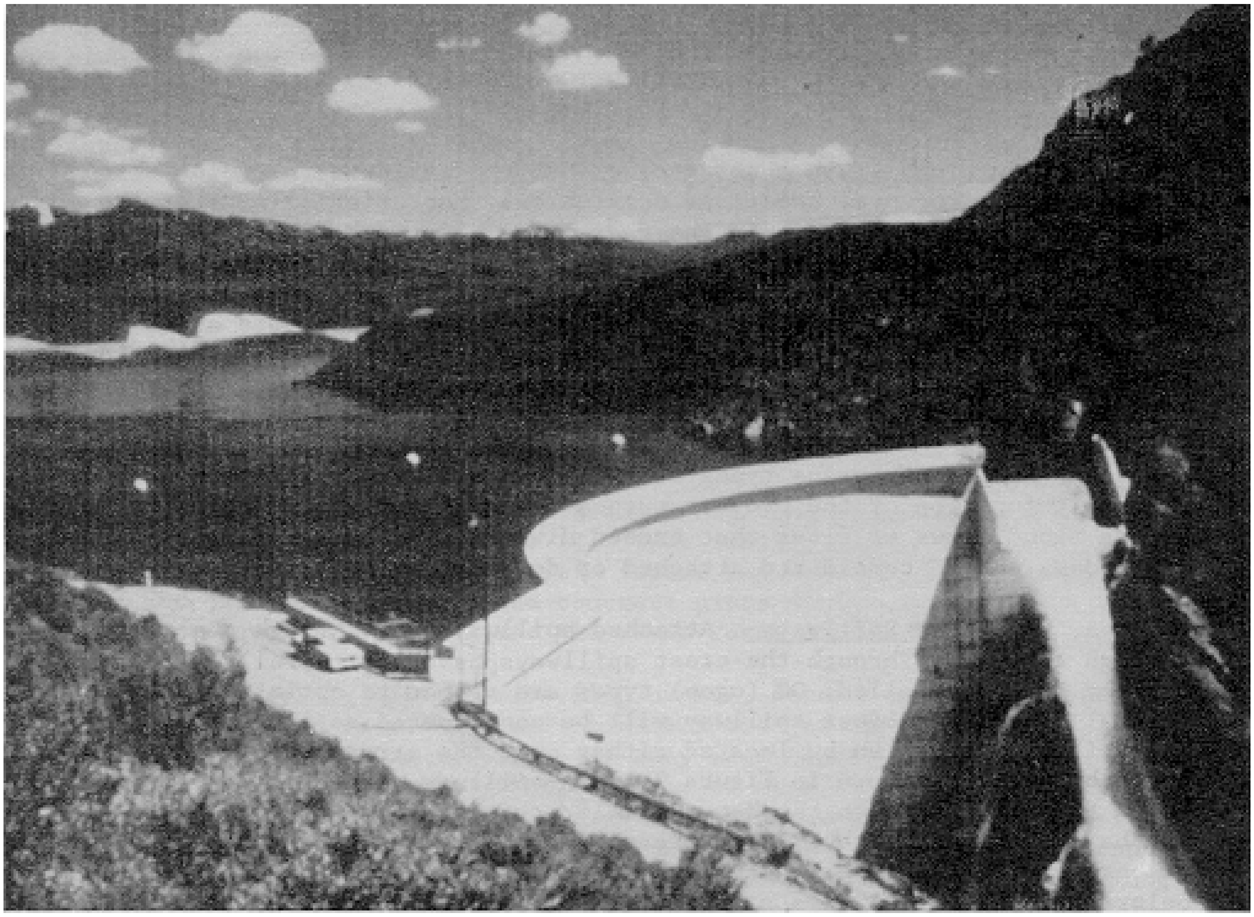


Figure 3-1. East Canyon Dam with spillway notch near left abutment (USBR)

valleys where the top arch is long compared to the structural height, such as a 5:1 crest length-to-height ratio, or in canyons where the climate fluctuates excessively (±50 °F) between summer and winter. In this latter case, winter temperature loads generally cause tensile stresses on both faces near the crest abutment, where the dam is thinnest and responds more quickly and dramatically than thicker sections. Thus, locating the spillway notches along the abutments is a natural structural location. The effects of a center notch, in addition to reducing arch action, are to require that concrete above the spillway crest support the reservoir load by cantilever action. Consequently, design of the vertical section must not only account for stresses from dead load and reservoir but meet stability requirements for shear. Temperature load in this portion of the dam is usually omitted from structural analyses. Earthquake loads also can become a problem and must be considered. On certain arch dams where the spillway width is a small proportion of the total crest length, some arch action will occur in the adjacent curved sections that will improve resistance to flood loads. Usually the beginning of this arch action is about the notch depth away from the pier. The more recent arch dams are thin efficient structures that make flood loads above the spillway crest of greater concern.

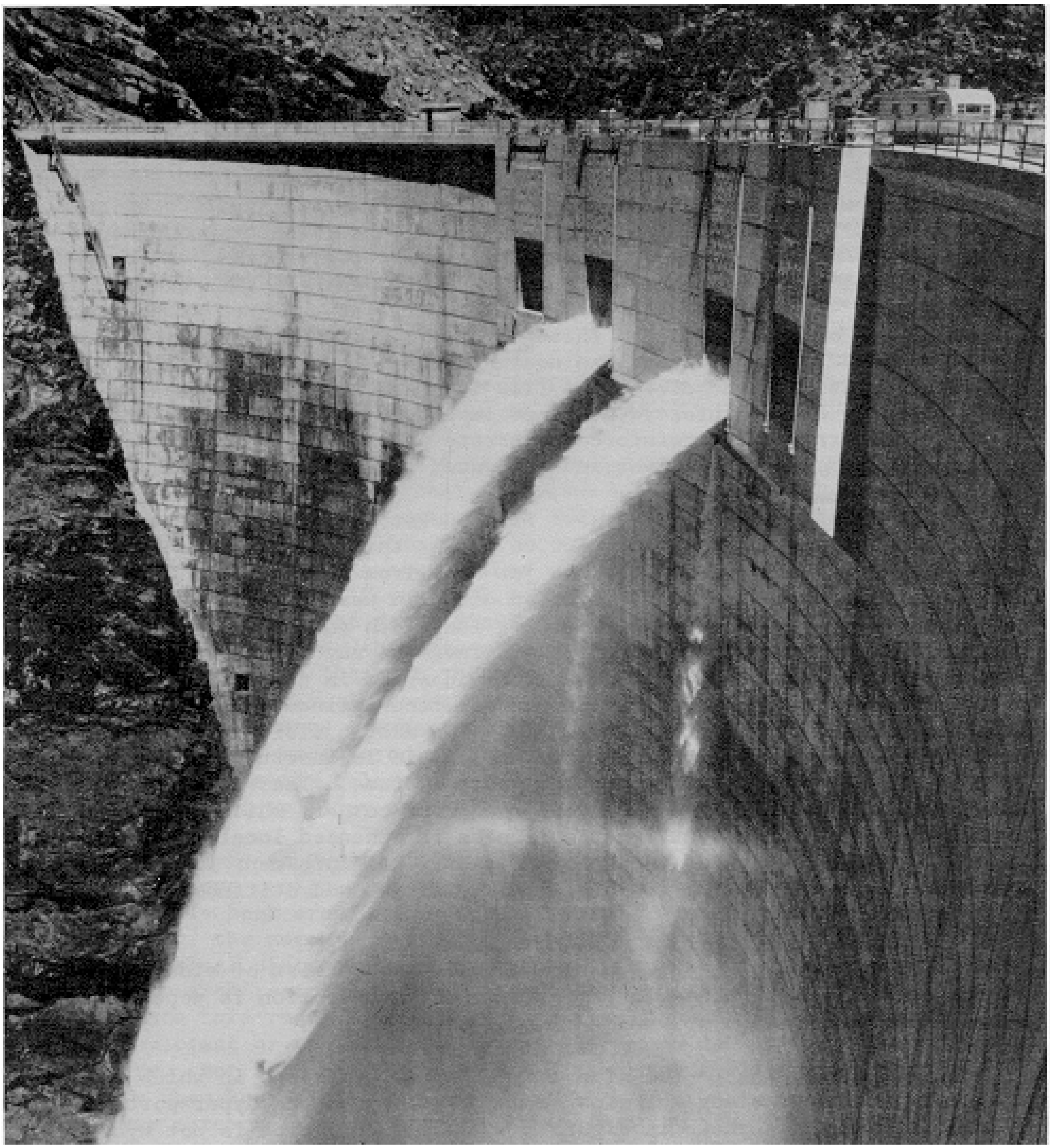


Figure 3-2. Through spillway below crest on Morrow Point Dam (USBR)

(2) Spillways Below Crest (thru Spillways). Spillways are constructed through the arch dam at some optimal distance below the dam crest to reduce the plunge and provide for additional discharge. The spillway may be visualized as multiple orifices, either round or rectangular, and controlled with some type of gates. The set of openings either may be centered over the streambed as shown in Figure 3-2 or split toward either or both abutments. The set is surrounded by mass concrete and locally reinforced to preserve, for the analyses, the assumption of a homogenous and monolithic structure. With this in mind, local reinforcement and/or added mass concrete must be designed so that the dam as a whole is not affected by the existence of the spillway. To minimize disruption of the flow of forces within the dam, the several openings should be aligned with the major principal compressive stresses resulting from the most frequent loading combination. Around the abutment, the major principal stresses on the downstream face are generally normal to the abutment. This alignment would tend to stagger the openings, thus creating design difficulties. In practice, however, all openings are aligned at the same elevation and oriented radially through the dam. If necessary, each orifice may be directed at a predetermined nonradial angle to converge the flows for energy dissipation or to direct the flow to a smaller impact area such as a stilling basin or a reinforced concrete impact pad. Between each orifice, within a set, are normal reinforced concrete piers designed to support the gravity load above the spillway and the water force on the gates.

(3) Flip Bucket. The massive flip bucket, depending on site conditions, may be located near the crest to direct the jet impact near the dam toe or farther down the face to flip the jet away from the toe. In either case, the supporting structure is constructed of solid mass concrete generally with vertical sides. By judiciously limiting its width and height, the supporting structure may be designed not to add stiffness to any of the arches or cantilevers. To assure this result, mastic is inserted in the contraction joints to the theoretical limits of the downstream face defined before the flip bucket was added as shown in Figure 3-3. The mastic disrupts any arch action that might develop. For the same reason, mastic is inserted during construction in the OG corbel overhang on the upstream face. These features protect the smooth flow of stresses and avoid reentrant corners which may precipitate cracking or spalling. Cantilever stiffness is enhanced locally but not enough to cause redistribution of the applied loads. Reinforcement in the supporting structure and accompanying training walls will not add stiffness to the arch dam.

b. Detached Spillways. Detached spillways consist of side channel, chute, tunnel, and morning glory spillways. The selection is dependent upon site conditions.

(1) Side Channel. The side channel spillway is one in which the control weir is placed along the side of and parallel to the upper portion of the discharge channel as shown in Figure 3-4. While this type is not hydraulically efficient nor inexpensive, it is used where a long overflow crest is desired to limit the surcharge head, where the abutments are steep, or where the control must be connected to a narrow channel or tunnel. Consequently, by being entirely upstream from the arch dam, the spillway causes no interference with the dam and only has a limited effect on the foundation. Similarly, along the upstream abutment, any spillway interference is mitigated by the usual low stresses in the foundation caused by the dam loads. Usually,

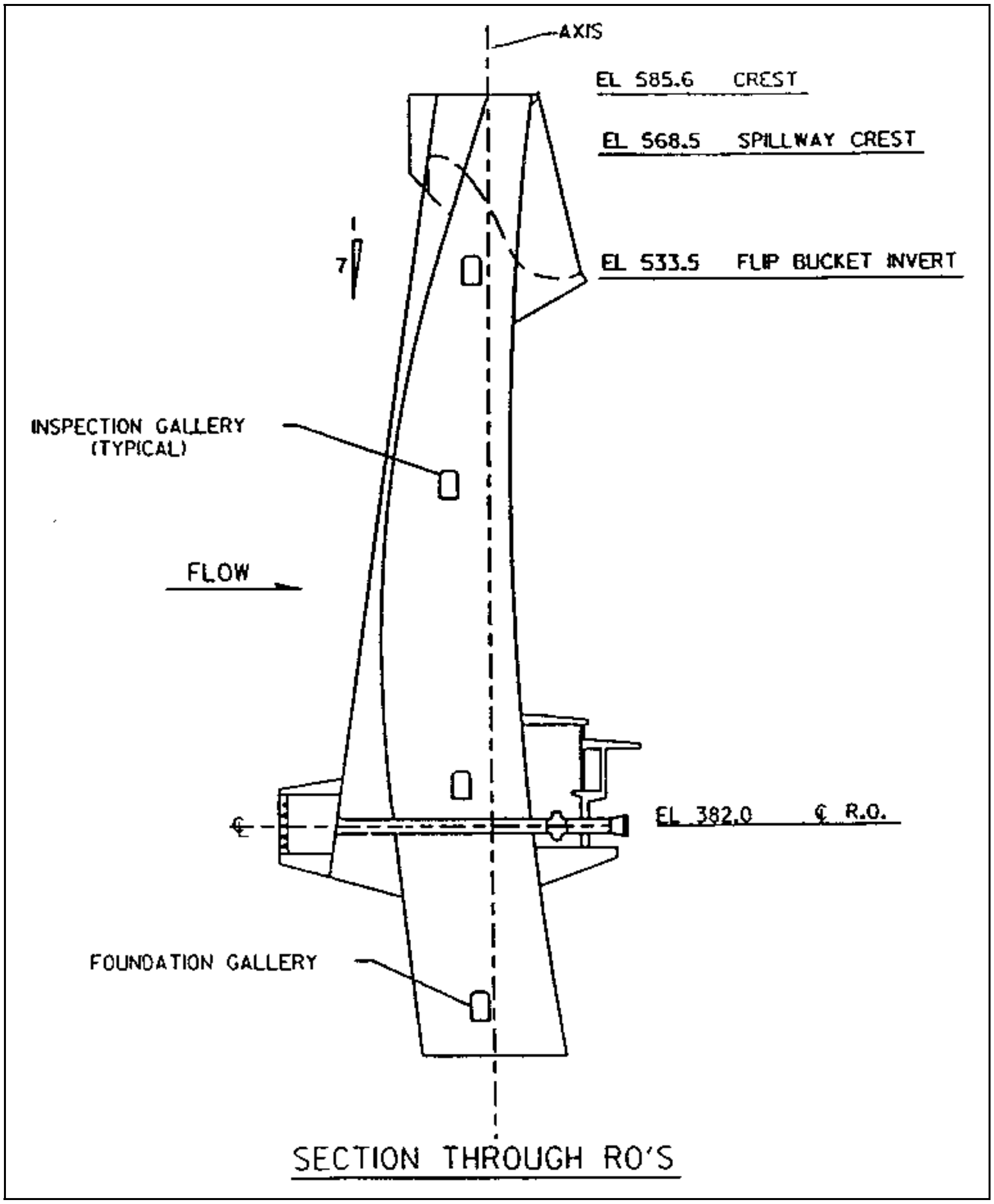


Figure 3-3. Typical section through spillway of a dam

stresses near the crest abutment are much less than the maximum allowable or, quite possibly, are tensile stresses.

(2) Chute Spillway. Chute spillways shown in Figure 3-5 convey discharge from the reservoir to the downstream river level through an open channel placed either along a dam abutment or through a saddle. In either case, the chute is not only removed from the main dam, but the initial slope by being flat isolates the remaining chute from the eventual stressed foundation rock.

(3) Tunnel Spillway. Tunnel spillways convey the discharge around the dam and consist of a vertical or inclined shaft, a large radius elbow, and a

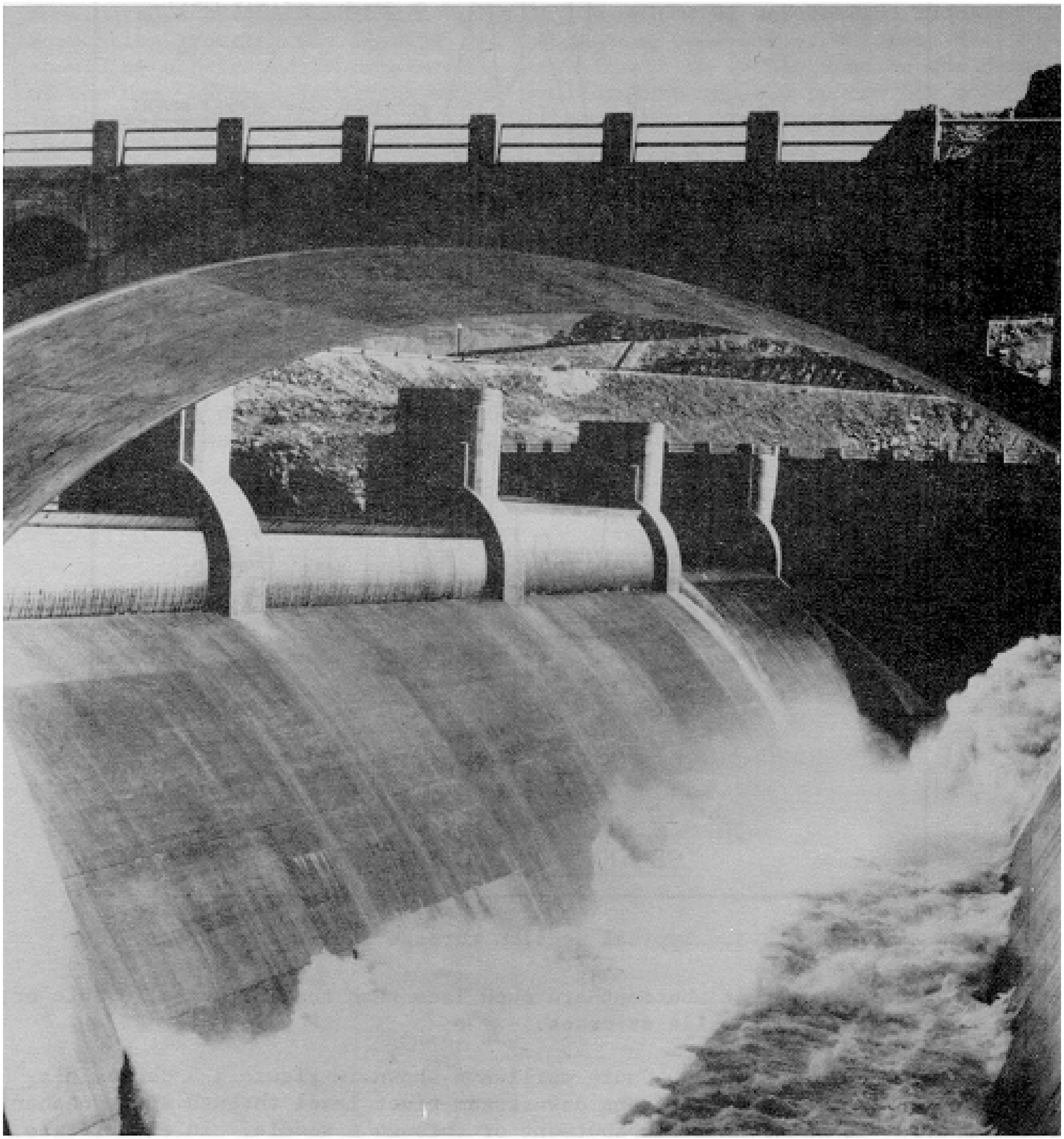


Figure 3-4. Side channel spillway at Hoover Dam (USBR)

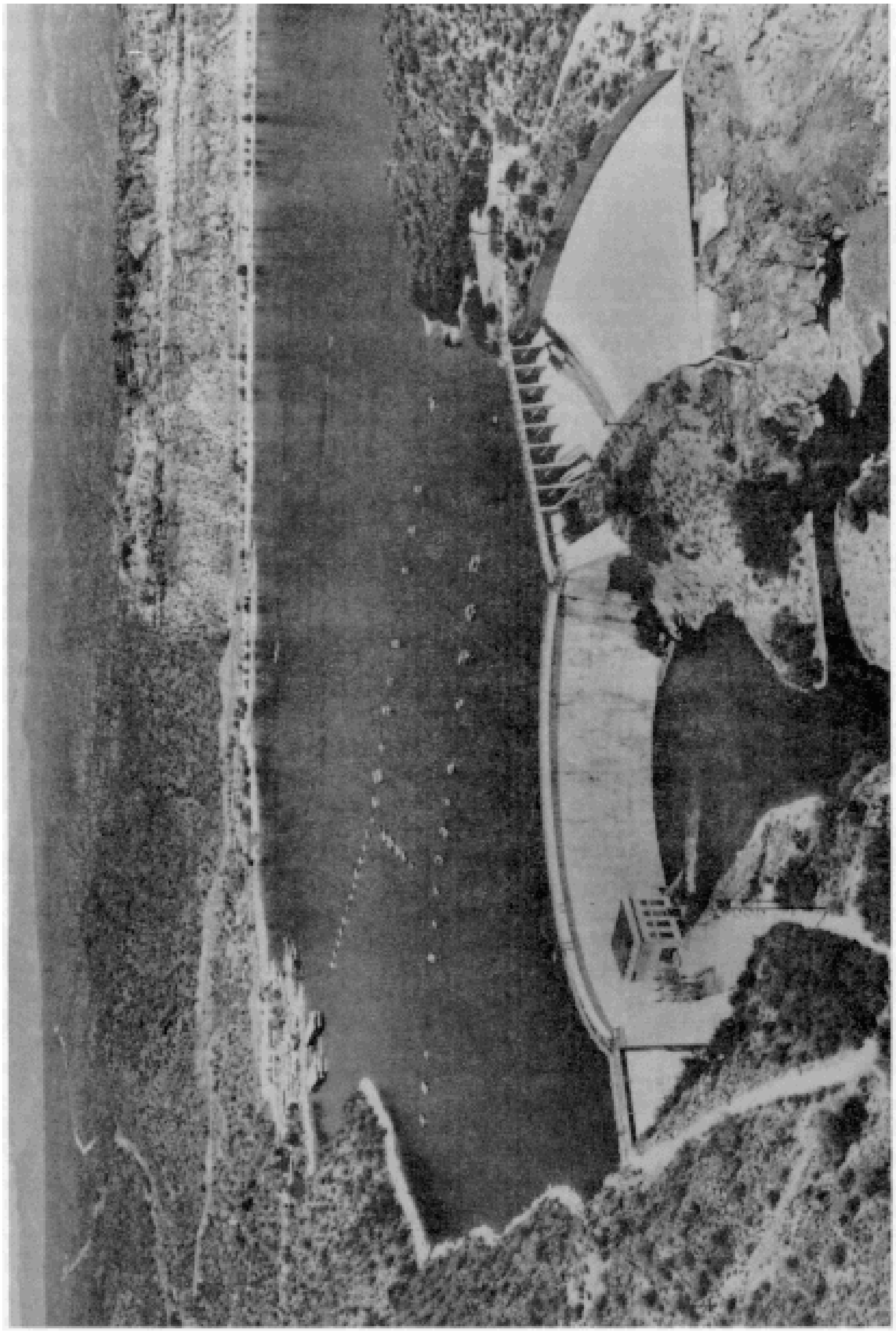


Figure 3-5. Chute spillway at Stewart Mountain Dam (USSR)

horizontal tunnel at the downstream end. Tunnel spillways may present advantages for damsites in narrow canyons with steep abutments or at sites where there is danger to open channels from snow or rock slides. The tunnel alignment usually traverses the stressed foundation and consequently should be at least one abutment thickness from the concrete to rock contact. Any need for increased spacing would be based on structural height and applied load combinations. Note that these tunnels are designed to flow up to 75 percent full, in which case in situ and superimposed stresses from the dam may govern the design. The corollary is that the tunnel walls must be strong enough to avoid creating a weakness in the foundation and subsequent stability problems with the dam.

(4) Morning Glory Spillway. A morning glory spillway such as that shown in Figure 3-6 is one in which the water enters over a horizontally positioned lip, which is circular in plan, and then flows to the downstream river channel through a horizontal or near horizontal tunnel. A morning glory spillway usually can be used advantageously at damsites in narrow canyons where the abutments rise steeply or where a diversion tunnel is available for use as the downstream leg. If a vertical drop structure is to be located upstream, it should not interfere structurally with the dam. A sloping tunnel offers the same concerns as previously discussed.

3-3. Outlet Works. Outlet works are a combination of structures and equipment required for the safe operation and control of water released from a reservoir to serve downstream needs. Outlet works are usually classified according to their purpose such as river outlets, which serve to regulate flows to the river and control the reservoir elevation, irrigation or municipal water supply outlets, which control the flow of water into a canal, pipeline, or river to satisfy specified needs, or, power outlets, which provide passage of water to turbines for power generation. In general, outlet works do not structurally impact the design of an arch dam as shown in Figure 3-7. The major difficulty may lie in adapting the outlet works to the arch dam, especially a small double-curvature thin arch dam where the midheight thickness may be 25 feet or less. Taller and/or heavier dams will have a significant differential head between the intake and the valve or gate house, and the conduit may have several bends. All of the features can be designed and constructed but not without some compromise. Outlet works should be located away from the abutments to avoid interference with the smooth flow of stresses into the rock and smooth flow of water into the conduit. A nominal distance of 10 diameters will provide sufficient space for convergence of stresses past the conduit.

a. Intake Structures. Intake structures, in addition to forming the entrance into the outlet works, may accommodate control devices and the necessary auxiliary appurtenances such as trashracks, fish screens, and bypass devices (Figure 3-8). An intake structure usually consists of a submerged structure on the upstream face or an intake tower in the reservoir. Vertical curvature on the upstream face may result in more than usual massive concrete components as shown in Figure 3-9 to provide a straight track for the stop logs or bulkhead gate. A compromise to relieve some of the massiveness is to recess portions of the track into the dam face. This recess which resembles a rectangular notch in plan reduces the stiffness of those arches involved not only at the notch but for some lateral distance, depending on the notch depth.

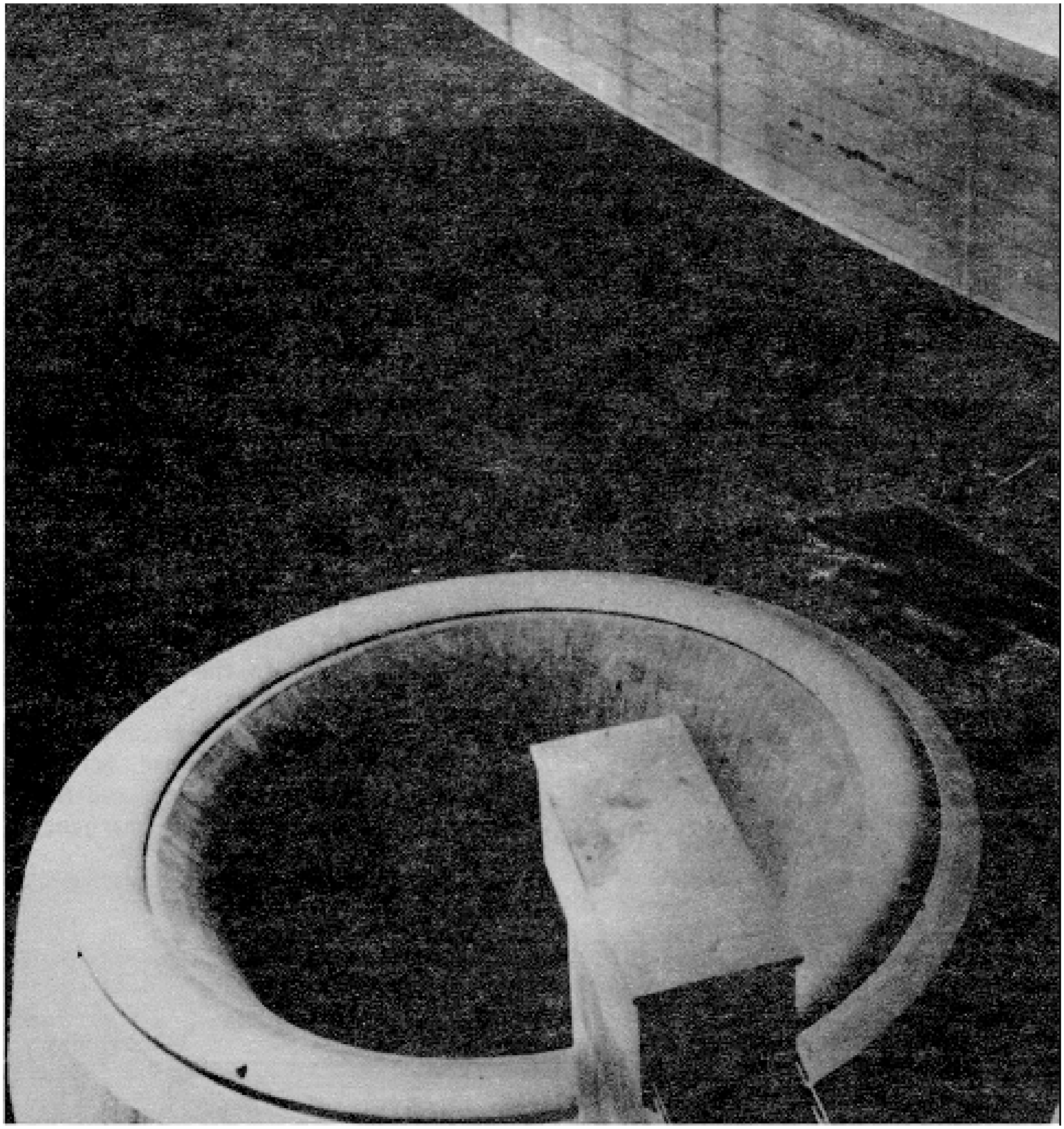
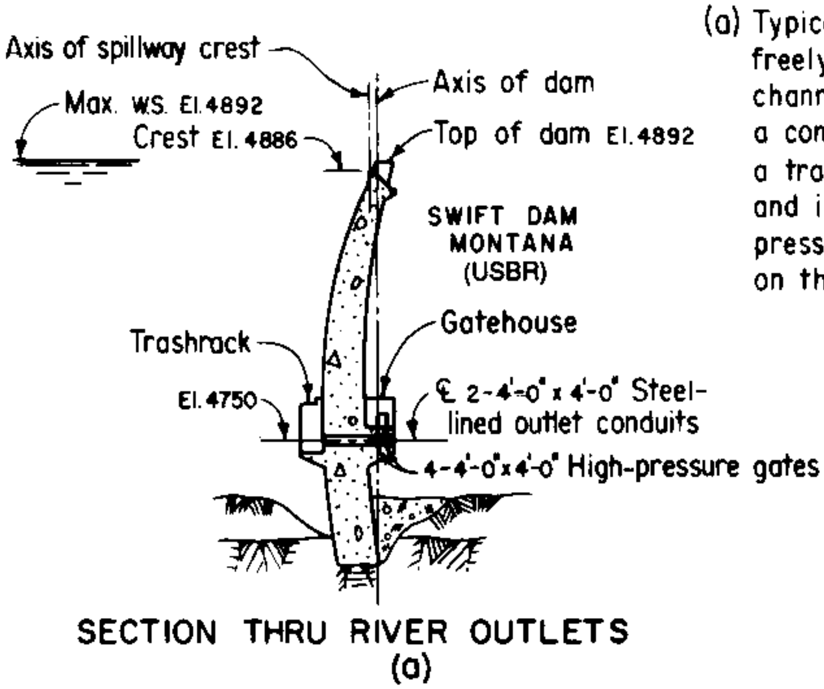
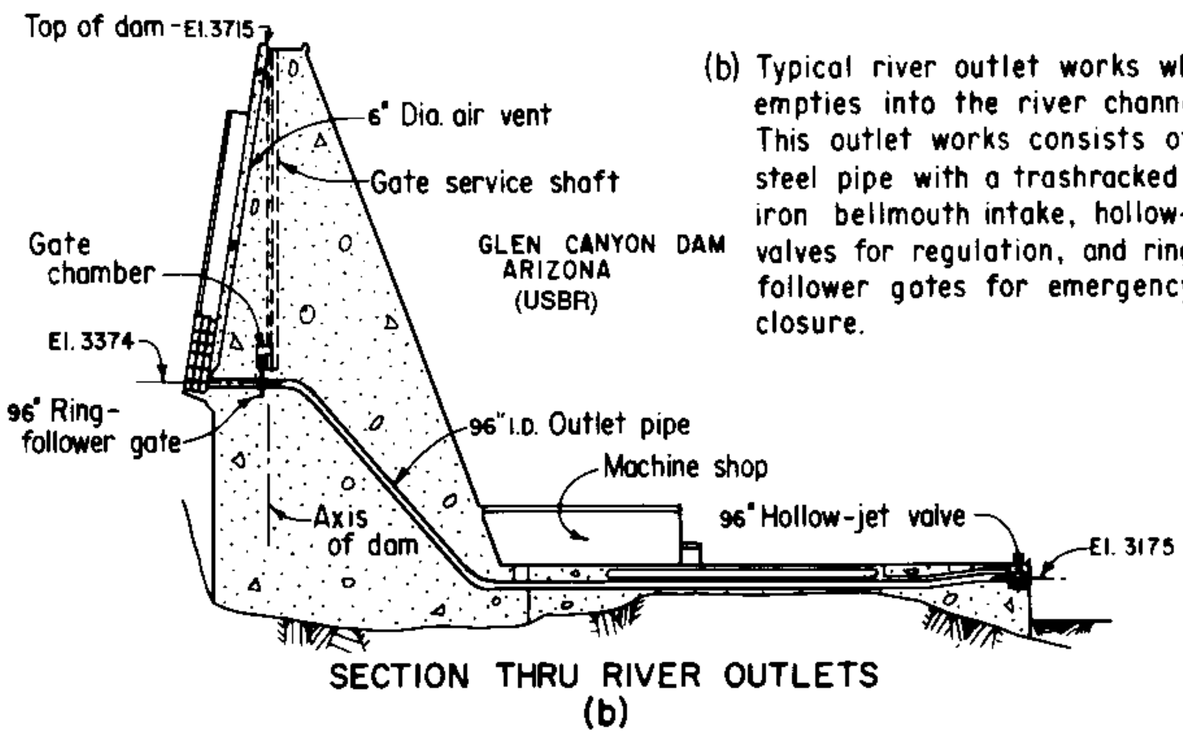


Figure 3-6. Morning glory spillway at Hungry Horse Dam. Note upstream face of dam in upper right (USBR)



(a) Typical river outlet works which freely discharges into the river channel. This outlet works is a conduit through the dam with a trashrack on the upstream face and is controlled by two high-pressure gates in a gatehouse on the downstream face of the dam



(b) Typical river outlet works which empties into the river channel. This outlet works consists of steel pipe with a trashracked cast iron bellmouth intake, hollow-jet valves for regulation, and ring-follower gates for emergency closure.

Figure 3-7. Typical river outlet works without a stilling basin

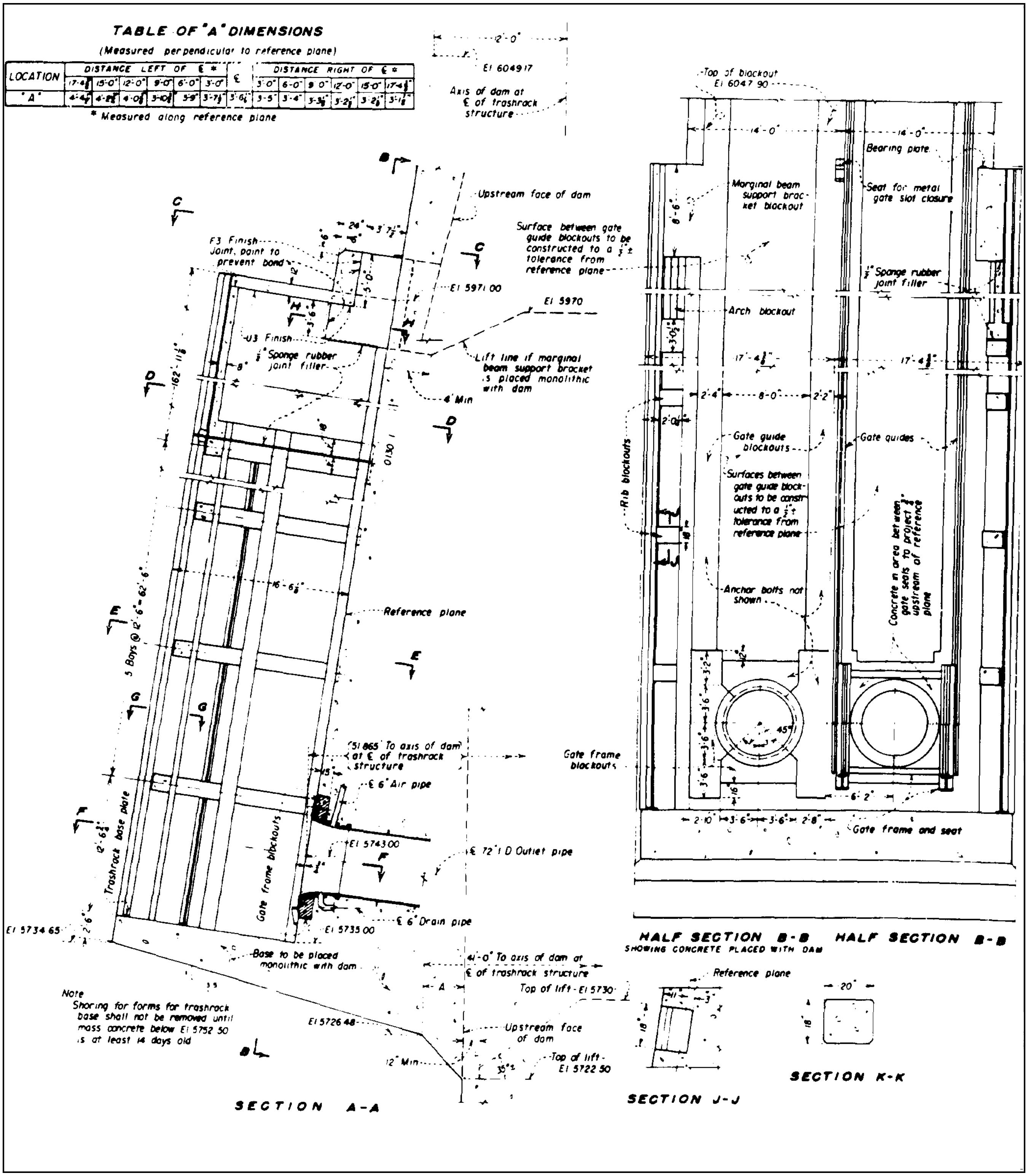


Figure 3-8. Typical river outlets trashrack structure (USBR)

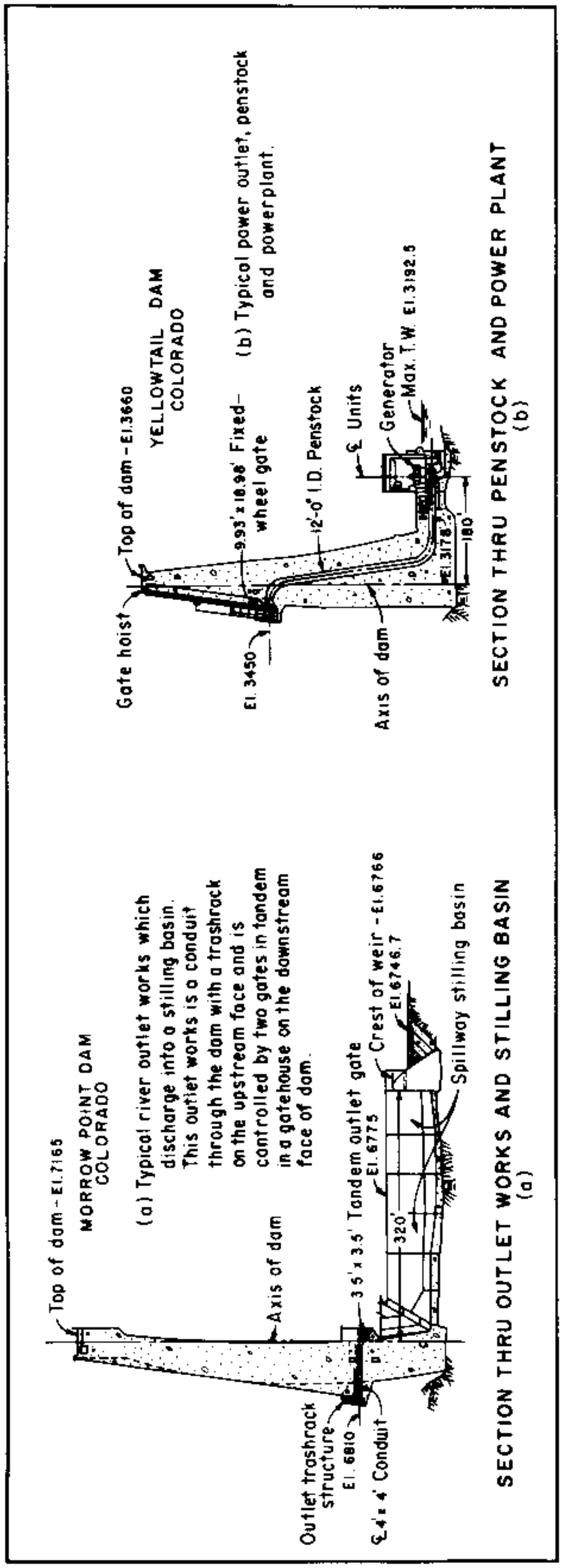


Figure 3-9. Typical river outlet works and power outlet (USBR)

b. Conduit. The outlet works conduit through a concrete dam may be lined or unlined, as in a power outlet, (Figure 3-10) but when the conduit is lined it may be assumed that a portion of the stress is being taken by the liner and not all is being transferred to the surrounding concrete. The temperature differential between the cool water passing through the conduit and the warmer concrete mass will produce tensile stresses in the concrete immediately adjacent to the conduit. In addition, the bursting effect from hydrostatic pressures will cause tensile stresses at the periphery of the conduit. Such tensile stresses and possible propagation of concrete cracking usually extend only a short distance in from the opening of the conduit. It is common practice to reinforce only the concrete adjacent to the opening. The most useful method for determining the stresses in the concrete surrounding the outlet conduit is the finite element method (FEM) of analysis.

c. Control House. The design of a control house depends upon the location and size of the structure, the operating and control equipment required, and the conditions of operation. The loadings and temperature conditions used in the design should be established to meet any situation which may be expected to occur during construction or during operation. In thin dams, the floor for the house is normally a reinforced concrete haunched slab cantilevered from the downstream face and designed to support the valves and houses. Neither the reinforcement nor the concrete should interfere with structural action of the arches and cantilevers. Emergency gates or valves are used only to completely shut off the flow in the outlet for repair, inspection maintenance or emergency closure. Common fixed wheel gates, such as shown in Figure 3-11, are either at the face or in a slot in the dam.

3-4. Appurtenances.

a. Elevator Tower and Shaft. Elevators are placed in concrete dams to provide access between the top of the dam and the gallery system, equipment and control chambers, and the power plant as shown in Figure 3-12. The elevator structure consists of an elevator shaft that is formed within the mass concrete and a tower at the crest of the dam. The shaft should have connecting adits which provide access into the gallery system and into operation and maintenance chambers. These adits should be located to provide access to the various galleries and to all locations at which monitoring and inspection of the dam or maintenance and control of equipment may be required. Stairways and/or emergency adits to the gallery system should be incorporated between elevator stops to provide an emergency exit such as shown in Figure 3-13. The design of reinforcement around a shaft can be accomplished by the use of finite element studies using the appropriate forces or stresses computed when analyzing the arch dam. In addition, stresses within the dam near the shaft due to temperature and other appropriate loads should be analyzed to determine if tension can develop at the shaft and be of such magnitude that reinforcement would be required. To minimize structural damage to the arches, the shaft should be aligned totally within the mass concrete and centered between the faces. However, the necessarily vertical shaft may not fit inside a thin arch dam. In such a case, the shaft could be moved to the abutment or designed to be entirely outside the dam but attached for vertical stability to the downstream face. This solution may not be esthetically pleasing, but it is functional, because if the shaft emerges through the downstream face it forms a rectangular notch that diverts the smooth flow of arch stresses and reduces arch stiffness.

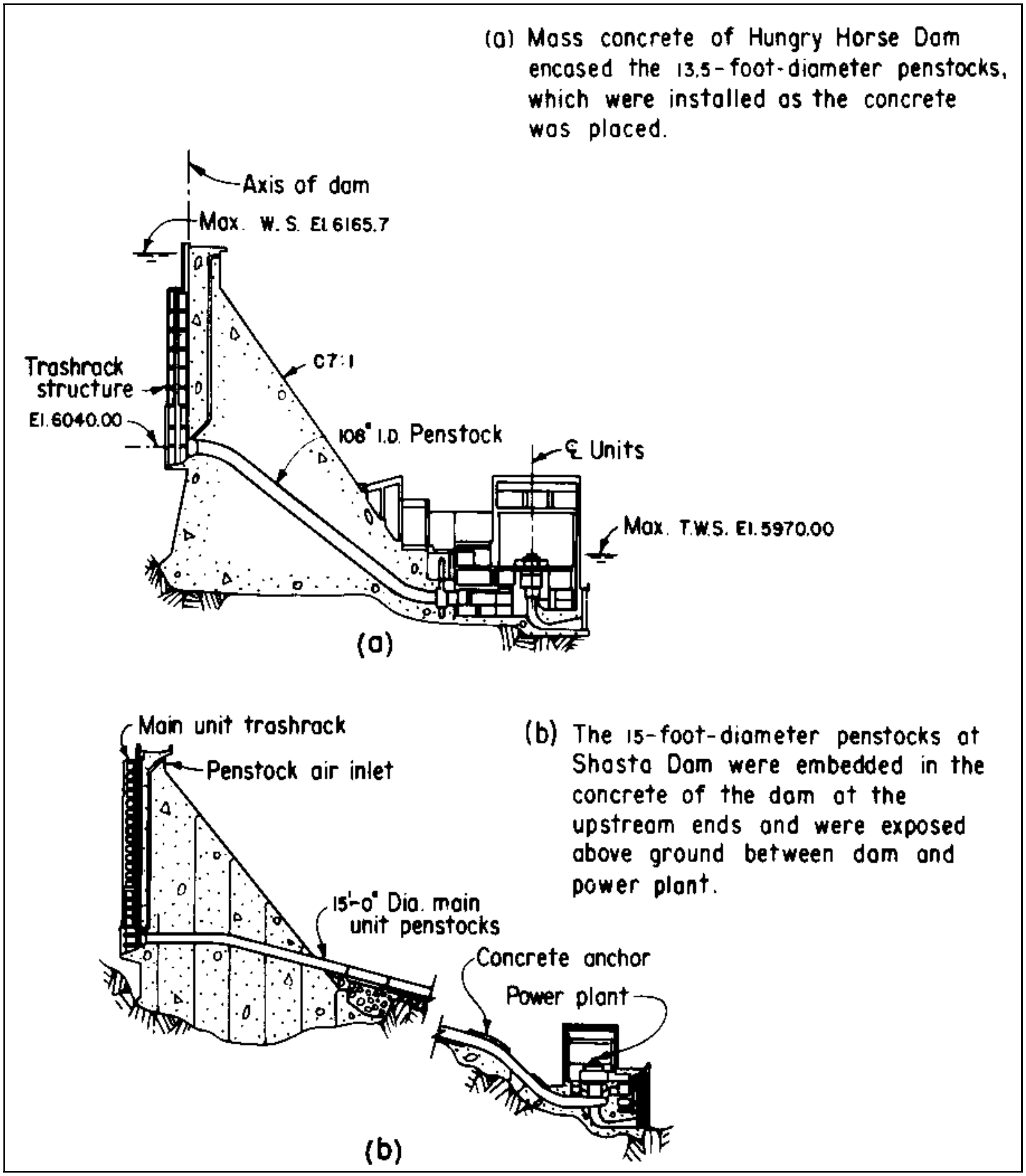


Figure 3-10. Typical penstock installations (USBR)

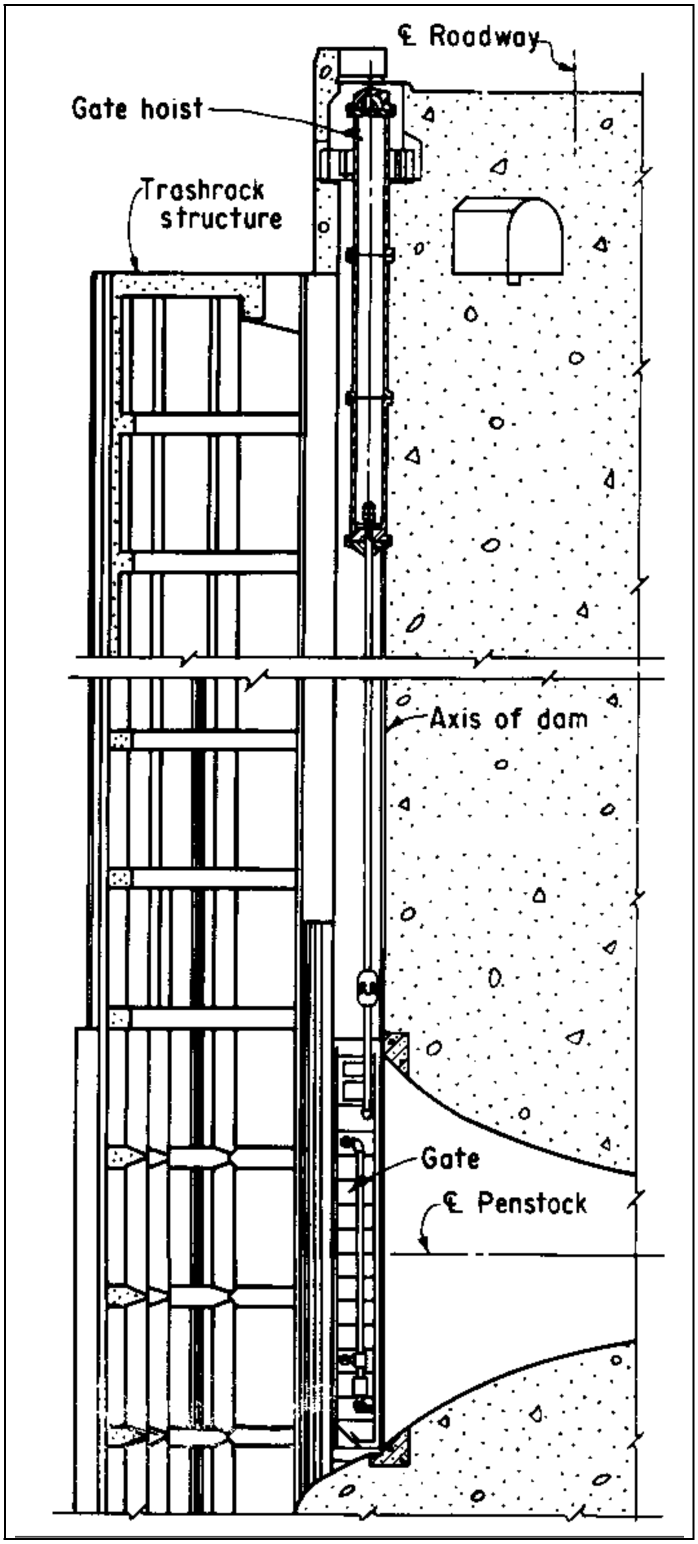


Figure 3-11. Typical fixed wheel gate installation at upstream face of dam (USBR)

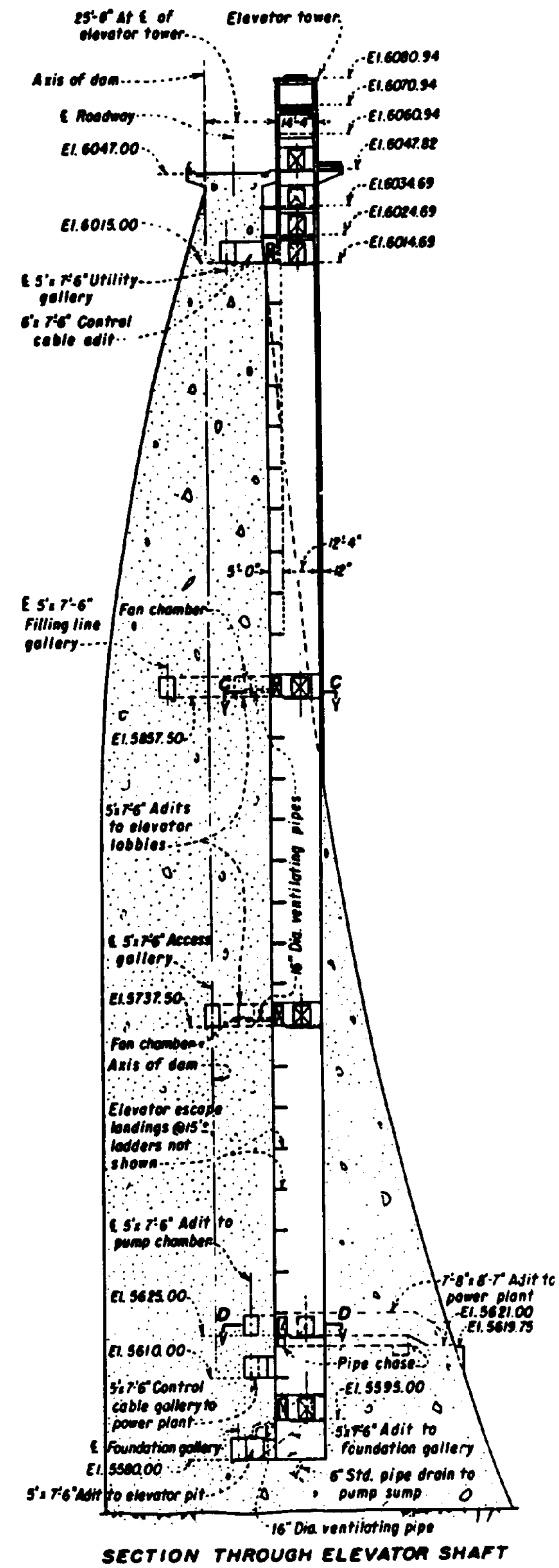


Figure 3-12. Structural and architectural layout of elevator shaft and tower in Flaming Gorge Dam (USBR) (Continued)

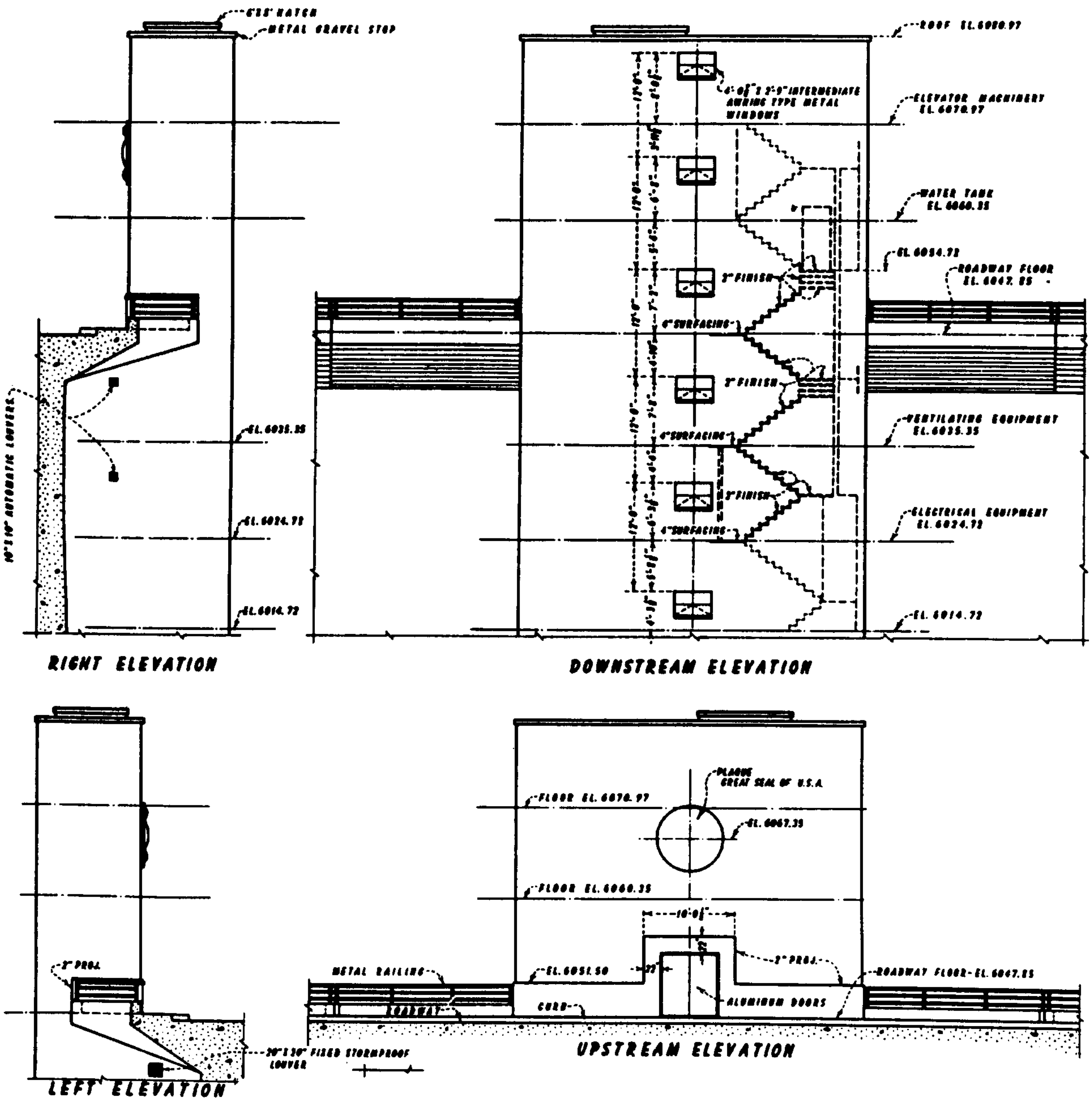


Figure 3-12. (Concluded)

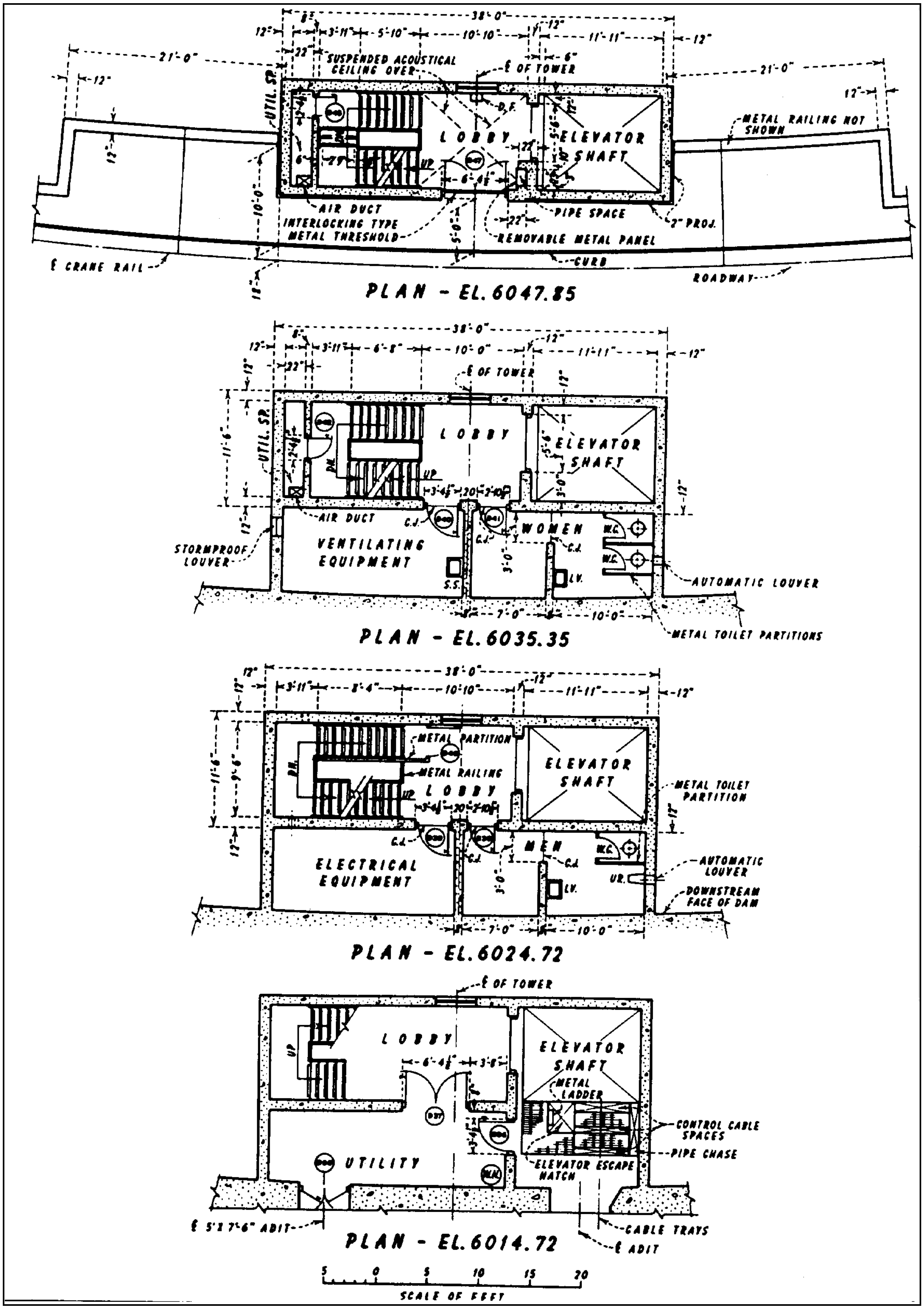


Figure 3-13. Details of layout of elevator shaft and tower in Flaming Gorge Dam (USBR)

b. Bridges. Bridges may be required on the top of the dam to carry a highway over the spillway or to provide roadway access to the top of the dam at some point other than its end. Design criteria for highway bridges usually conform to the standard specifications adopted by the American Association of State Highway Officials and are modified to satisfy local conditions and any particular requirement of the project. Bridges, regardless of how heavy, whether of steel or concrete, or with fixed or pinned connections, are not considered sufficiently strong to transfer arch loads from one mass concrete pier to the other.

c. Top of the Dam. The top of the dam may contain a highway, maintenance road, or walkway such as shown in Figure 3-14. If a roadway is to be built across the dam, the normal top of the dam can be widened with corbels which cantilever the road or walkway out from the upstream or downstream faces of the dam. The width of the roadway on the top of the dam is dependent upon the type and size of roadway, sidewalks, and maintenance and operation space needed to accomplish the tasks required. Parapets or handrails are required both upstream and downstream on the top of the dam and should be designed to meet safety requirements. The minimum height of parapet above the sidewalk should be 3 feet 6 inches. A solid upstream parapet may be used to increase the freeboard if additional height is needed. The design of the reinforcement for the top of the dam involves determining the amount of reinforcement required for the live and dead loads on the roadway cantilevers and any temperature stresses which may develop. Temperature reinforcement required at the top of the dam is dependent upon the configuration and size of the area and the temperature condition which may occur at the site. After the temperature distributions are determined by studies, the temperature stresses that occur can be analyzed by use of the FEM. If a roadway width greater than the theoretical crest thickness of the dam is required, the additional horizontal stiffness of the roadway section may interfere with the arch actions at the top if the dam. To prevent such interference, horizontal contraction joints should be provided in the roadway section with appropriate joint material. The contraction joints should begin at the edge of the roadway and extend to the theoretical limits of the dam face. Live loads such as hoists, cranes, stoplogs, and trucks are not added to the vertical loads when analyzing the arch dam; these loads may weigh less than 10 cubic yards (cu yd) of concrete, an insignificant amount in a concrete dam.

d. Galleries and Adits. A gallery is a formed opening within the dam to provide access into or through the dam. Galleries are either transverse or longitudinal and may be horizontal or on a slope as shown in Figure 3-15. Galleries connecting other galleries or connecting with other features such as power plants, elevators, and pump chambers are called adits. Some of the more common uses or purposes of galleries are to provide a drainageway for water percolating through the upstream face or seeping through the foundation, space for drilling and grouting the foundation, space for headers and equipment used in artificially cooling the concrete blocks and for grouting contraction joints, access to the interior of the structure for observing its behavior, access to and room for mechanical and electrical equipment, access through the dam for control cables and/or power cables, and access routes for visitors, as shown in Figure 3-16. The location and size of a gallery will depend on its intended use or purpose. The size is normally 5 feet wide by 7.5 feet high. In small, thin arch dams, galleries are not used where the radial thickness is less than five times the width. This gives the cantilevers sufficient section

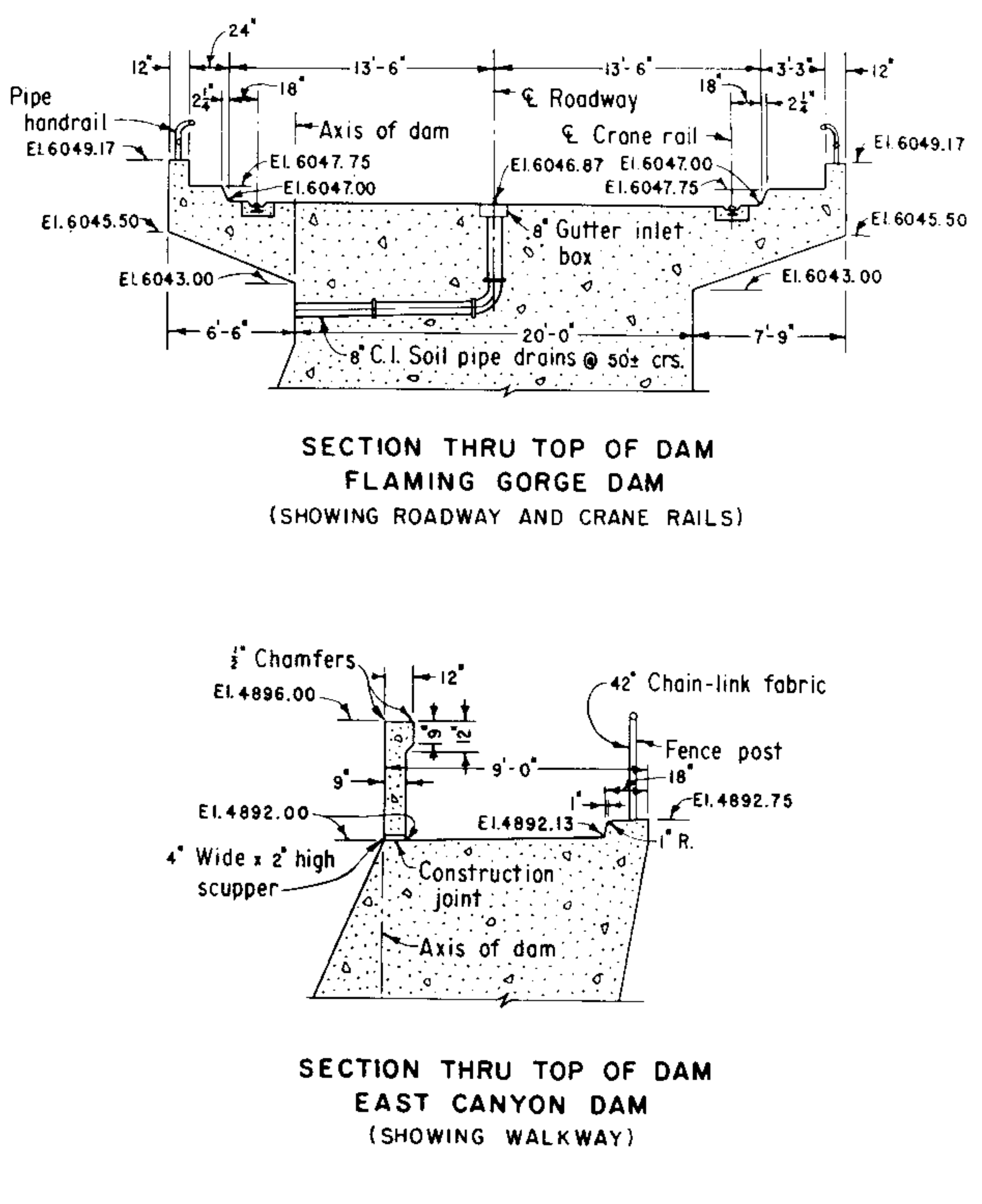


Figure 3-14. Typical sections at top of an arch dam (USBR)

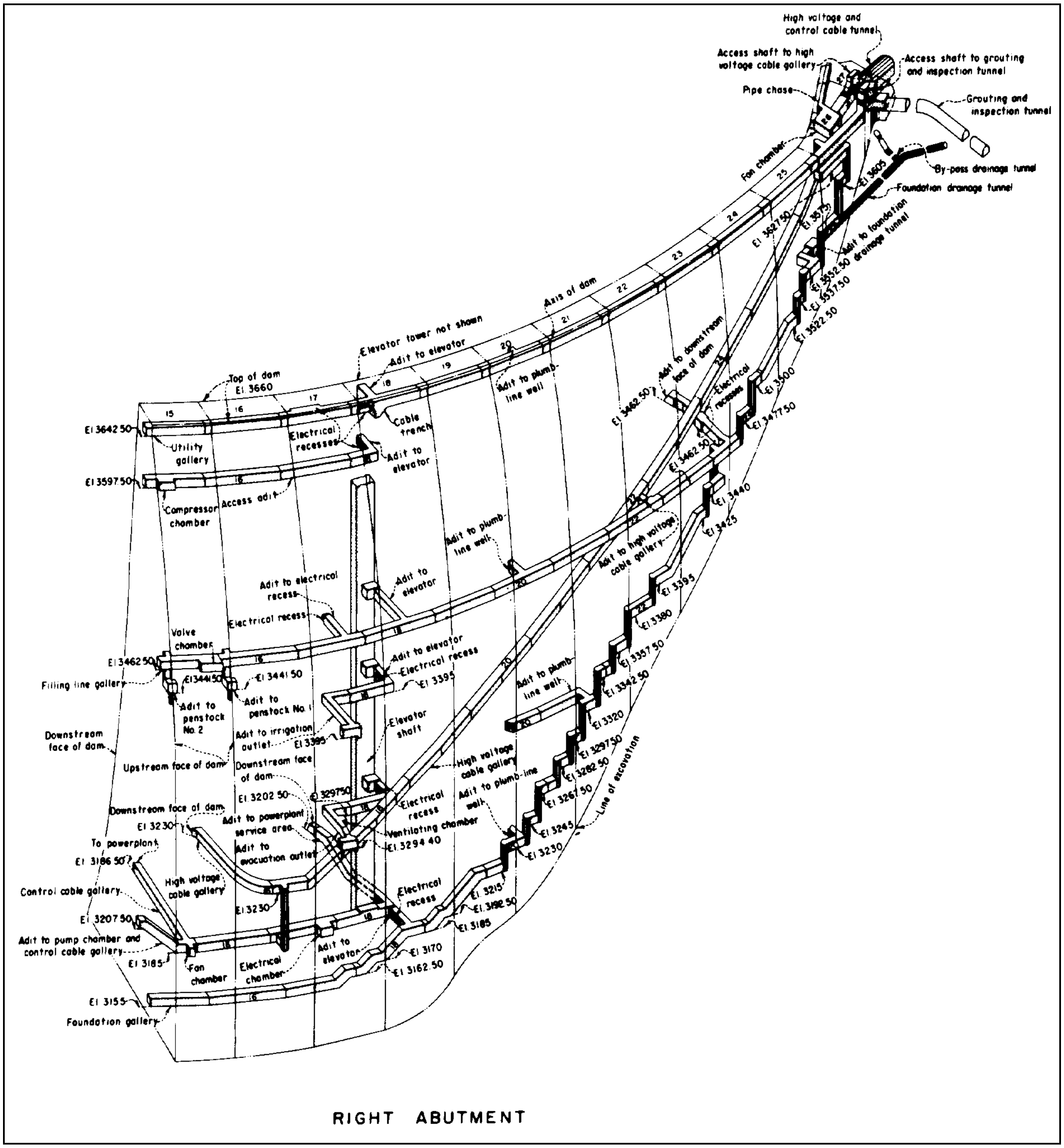


Figure 3-15. Gallery system in right side of Yellowtail Dam (USBR)

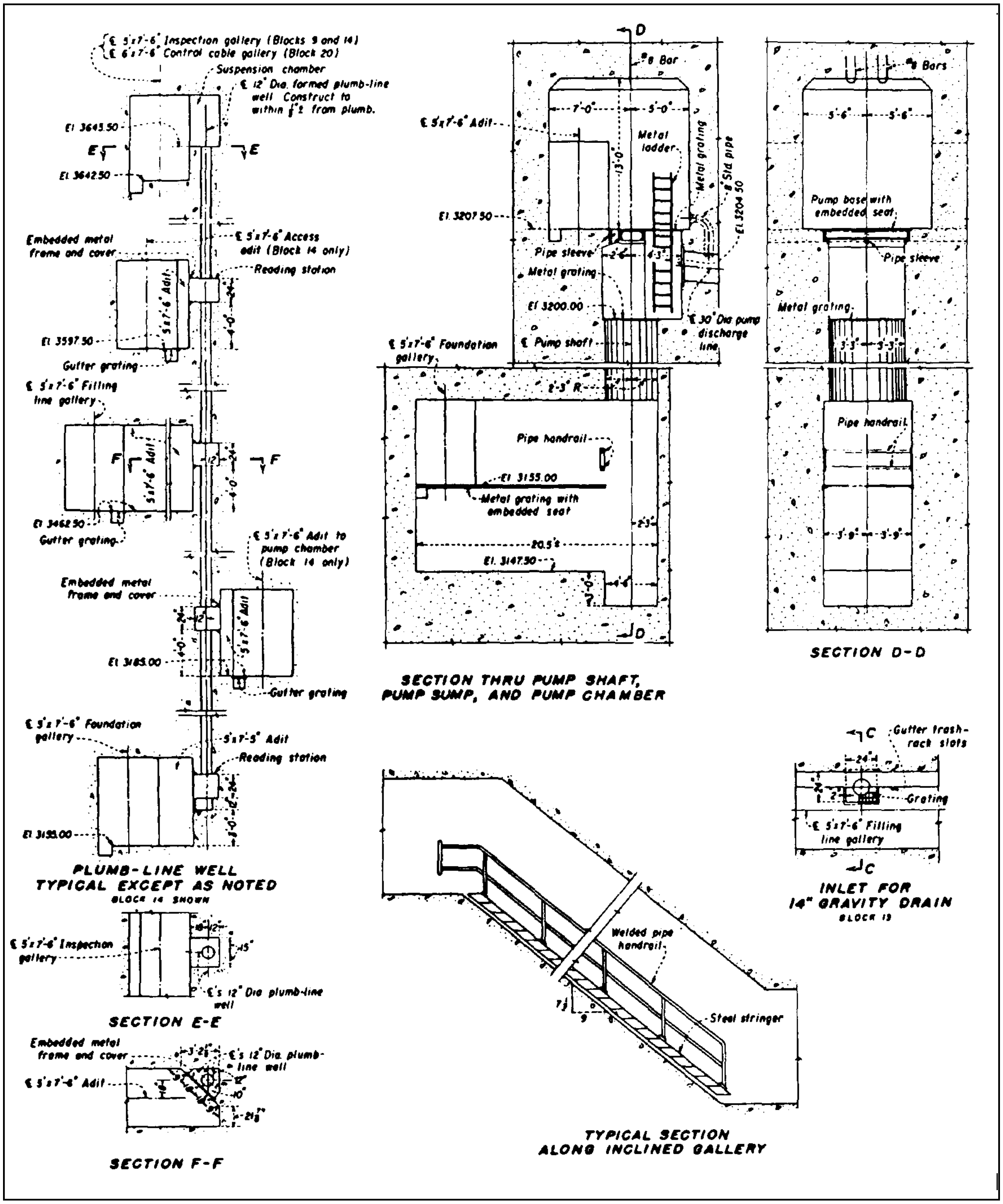


Figure 3-16. Details of galleries and shafts in Yellowtail Dam (USBR) (Continued)

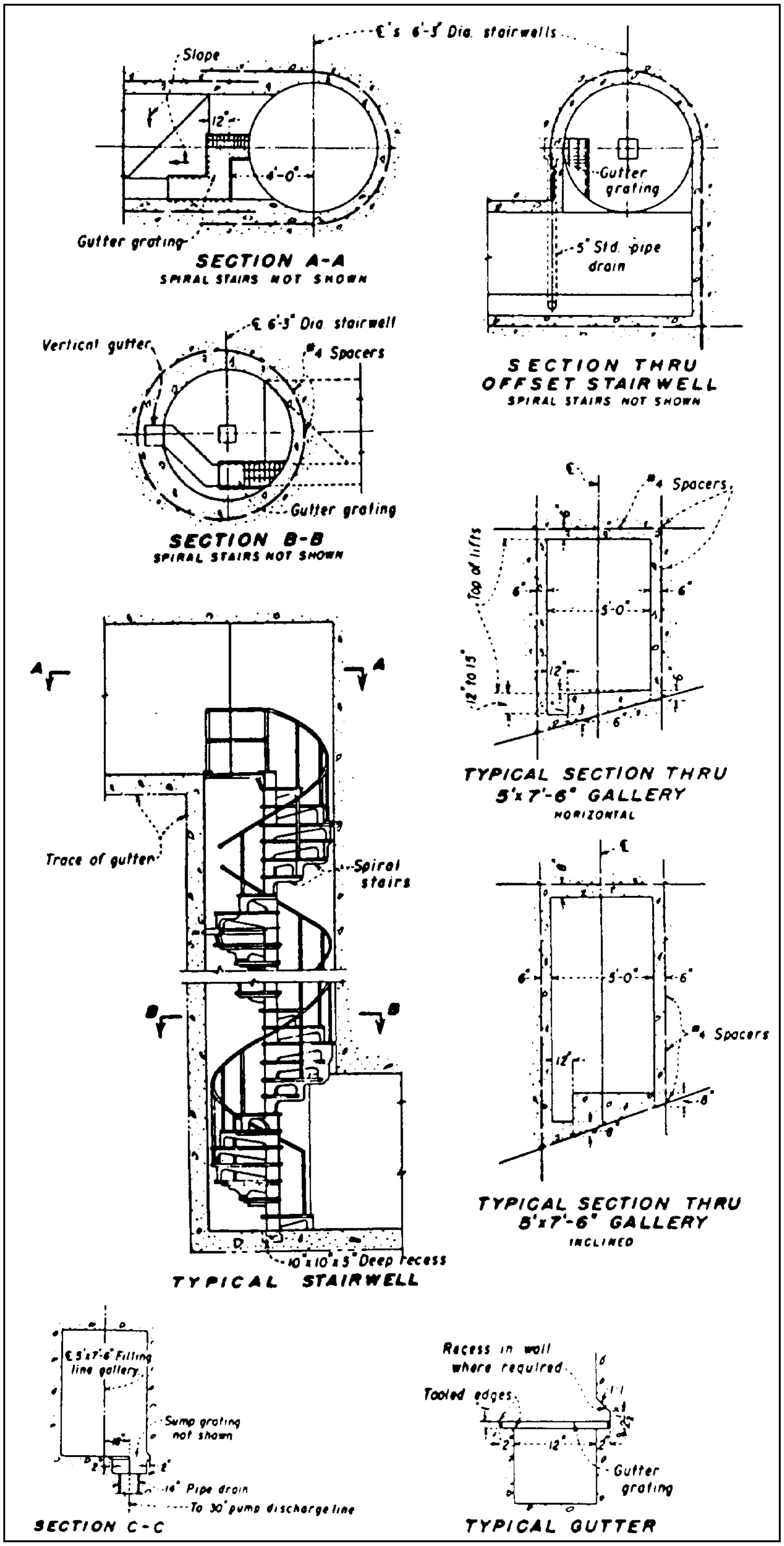


Figure 3-16. (Concluded)

modulus to perform as intended. A distance of two diameters on either side of the gallery provides sufficient thickness to mitigate the high vertical stresses that concentrate along the gallery walls and to develop the necessary section modulus. In thin arch dams, access galleries can be designed smaller than 5 feet wide such as an elliptically shaped gallery 2 feet wide by 8 feet high that contains lighting across the top, a noncorrosive grating for pedestrian traffic, and provides space for drainage.

3-5. Restitution Concrete. Because of topographical and geological features, all damsites are nonsymmetrical and have an irregular profile; however, during the design of an arch dam, a significant saving in keyway excavation may be achieved by building up certain regions of the footprint with mass concrete to form an artificial foundation and provide a smooth perimeter for the dam. At a particular site, restitution concrete may be local "dental" concrete, the more extensive "pad," or "thrust blocks" along the crest. In each case, the longitudinal and transverse shape is different for different design purposes, and, accordingly, restitution concrete may be extensive upstream, downstream, or around the perimeter of the dam. In keeping with the concept of efficiency and economy, each arch dam design should be made as geometrically simple as possible; the optimum is a symmetrical design. With this in mind, restitution concrete can be added to the foundation to smooth the profile and make the site more symmetrical, and/or provide a better distribution of stresses to the foundation. Restitution concrete is added to the rock contact either before or during construction; the concrete mix is the same mass concrete used to construct the dam.

a. Dental Concrete. Dental concrete is used to improve local geological or topographical discontinuities that might adversely affect stability or deformation as shown in Figure 3-17. Discontinuities include joints, seams, faults, and shattered or inferior rock uncovered during exploratory drilling or final excavation that make complete removal impractical. The necessary amount of concrete replacement in these weak geological zones is usually determined from finite element analyses in which geologic properties, geometric limits, and internal and/or external loads are defined. For relatively homogenous rock foundations with only nominal faulting or shearing, the following approximate formulas can be used for determining the depth of dental treatment:

$$d = 0.002bH + 5 \text{ for } H \text{ greater than or equal to 150 feet}$$
$$d = 0.3b + 5 \text{ for } H \text{ less than 150 feet}$$

where

H = height of dam above general foundation level, in feet
b = width of weak zone, in feet, and
d = depth of excavation of weak zone below surface of adjoining sound rock, in feet

b. Pad. A concrete pad is added to the foundation to smooth the arch dam profile, to make the site more symmetrical, to reduce excavation, and/or to provide a better distribution of stresses on the foundation. To smooth the profile, pad concrete is placed around the arch dam perimeter, made irregular due to topography or geology, such as in box canyons or bridging low-strength rock types. Such treatment is not unique to the United States. The

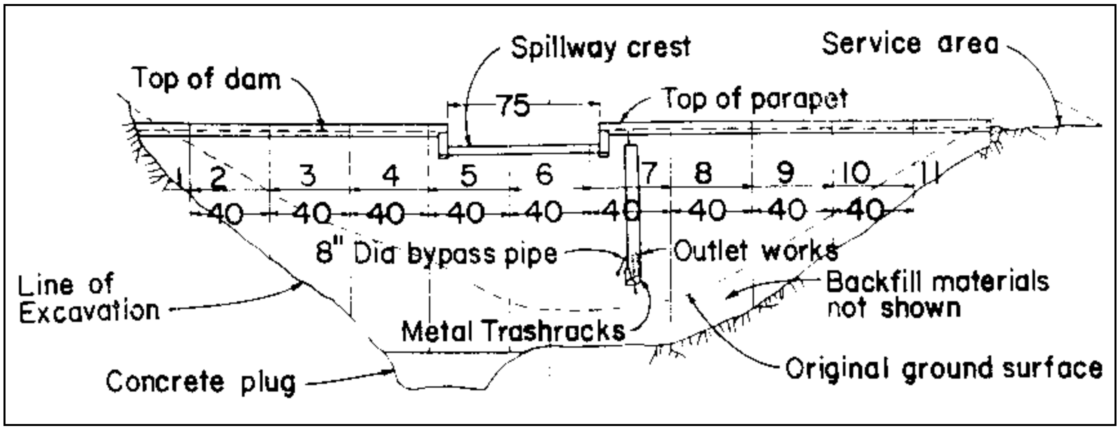


Figure 3-17. Upstream elevation of Wildhorse Dam. Note dental concrete (concrete plug) (USBR)

additional thickness along the abutment is called a socle in Portugal. Arch dams in nonsymmetrical sites can be designed more efficiently by constructing a pad along the abutment of the long side. Reduced excavation is accomplished by filling in a single but prominent depression with a pad rather than excavating the entire abutment to smooth the profile. The pad, because it is analogous to a spread footing, will reduce pressure and deformation, especially on weak rock.

(1) The pad in cross section has the geometric shape of a trapezoid. The top surface of the trapezoid then becomes the profile for the arch dam. To develop a smooth profile for the arch dam, the trapezoidal height will vary along the contact. The size of the footing is a function of the arch abutment thickness. At the contact of the arch and the pad, the pad thickness is greater than the arch thickness by a nominal amount of 5 feet, or greater, as determined from two-dimensional (2-D) finite element studies. The extra concrete thickness, analogous to a berm, is constructed on both faces. This berm provides geometric and structural delineation between the dam and the pad. Below the berm, the pad slopes according to the canyon profile. The slope is described in a vertical radial plane. In a wide valley where gravity action is predominant, a nominal slope of 1:1 is suggested on the downstream side. In narrow canyons, where arch action is the major structural resistance, the slope may be steeper. The upstream face may be sloped or vertical depending on the loading combinations. For example, reservoir drawdown during the summer coupled with high temperatures will cause upstream deflection and corresponding larger compressive stresses along the heel. Thus, to simulate the abutment the upstream face should be sloped upstream. Otherwise, a vertical or near vertical face will suffice. Normally, a constant slope will be sufficient, both upstream and downstream. A pad should be used to fill depressions in the profile that would otherwise cause overexcavation and to smooth the profile or to improve the site symmetry.

(2) The appropriate shape should be evaluated with horizontal and vertical sections at points on the berm. Classical shallow beam structural analyses are not applicable because the pad is not a shallow beam. For completeness, check the shape for stress and stability at several representative locations around the perimeter. Loads to be considered in structural design of the pad include moment, thrust, and shear from the arch dam, as well as the

reservoir pressure. The load on the massive footing for a cantilever should also include its own weight. Two-dimensional FEMs are ideally suited to shape and analyze the various loads and load combinations. Reshaping and reanalysis then can also be easily accomplished.

(3) Construction of the pad may occur before or during construction of the arch dam. For example, if the foundation rock is very hard and/or massive, higher-strength concrete can be placed months before the arch is constructed. In this way, the pad concrete has time to cure and perhaps more closely approximate the actual foundation conditions. Or, as with the socle where a slightly different geometric shape is required at the arch abutment than at the top of the footing, the more efficient method is to construct the footing monolithic with the arch dam, in blocks, and lifts. Special forming details are necessary at the berm; above and below the berm, normal slip forming is sufficient. Artificial cooling and contraction joint grouting is recommended to avoid radial crack propagation into the dam from future shrinkage and settlement. As with the arch dam, no reinforcing steel is necessary in the foundation shaping concrete. Longitudinal contraction joints should be avoided to prevent possible tangential crack propagation into the dam. If, during construction, a significant crack should appear in the foundation or dam concrete and continue to run through successive lifts, a proven remedy is to provide a mat of reinforcing steel on the next lift of the block with the crack but not necessarily across contraction joints.

c. Thrust Blocks. Thrust blocks are another type of restitution concrete. These components are constructed of mass concrete on foundation rock and form an extension of the arch dam crest. They are particularly useful in sites with steep side slopes extending about three-fourths the distance to the top and then rapidly flattening. In such a site, significantly additional water storage can be achieved by thrust blocks without a proportional increase in costs. For small and short extensions beyond the neat line, the cross-sectional shape can simply be a continuation of arch dam geometry as shown on Figure 3-18; thus, for some distance past the neat line, arch action will resist some of the applied load. Beyond that distance, cantilever action resists the water load and must be stable as with a gravity dam. The extension may be a straight tangent or curved as dictated by the topography, as shown in Figure 3-19. If curved, the applied load is distributed horizontally and vertically, in which case the section can be thinner than a straight gravity section. If straight, the tangent section will exhibit some horizontal beam action, but conservatively, none should be assumed unless artificial cooling and contraction joint grouting are utilized. For cases where the thrust block sections are shaped as gravity dams, the analysis approximates the thrust block stiffness by reducing the foundation modulus on those arches connected to the thrust blocks. A reasonable value for the crest abutments is 100 kips per square inch (ksi). The abutment/foundation modulus should be linearly interpolated at elevations between the crest and the first lower arch abutting on rock. The reliability of this assumption should be tested by performing parametric studies with several different assumed rock moduli, comparing arch and cantilever stresses on each face, and noting the stress differences in the lower half of the dam. In general, stress differences should be localized around the thrust blocks.

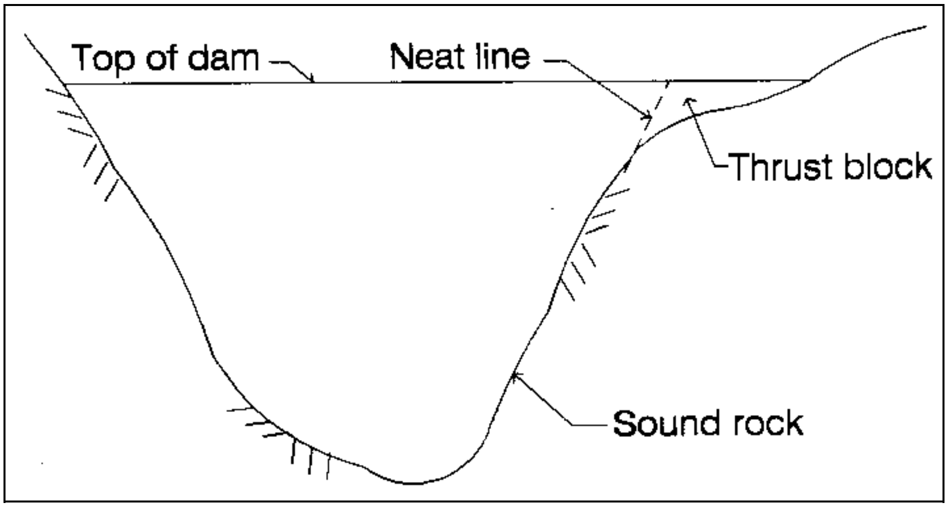


Figure 3-18. Schematic elevation of simple thrust block as a right abutment extension of an arch dam

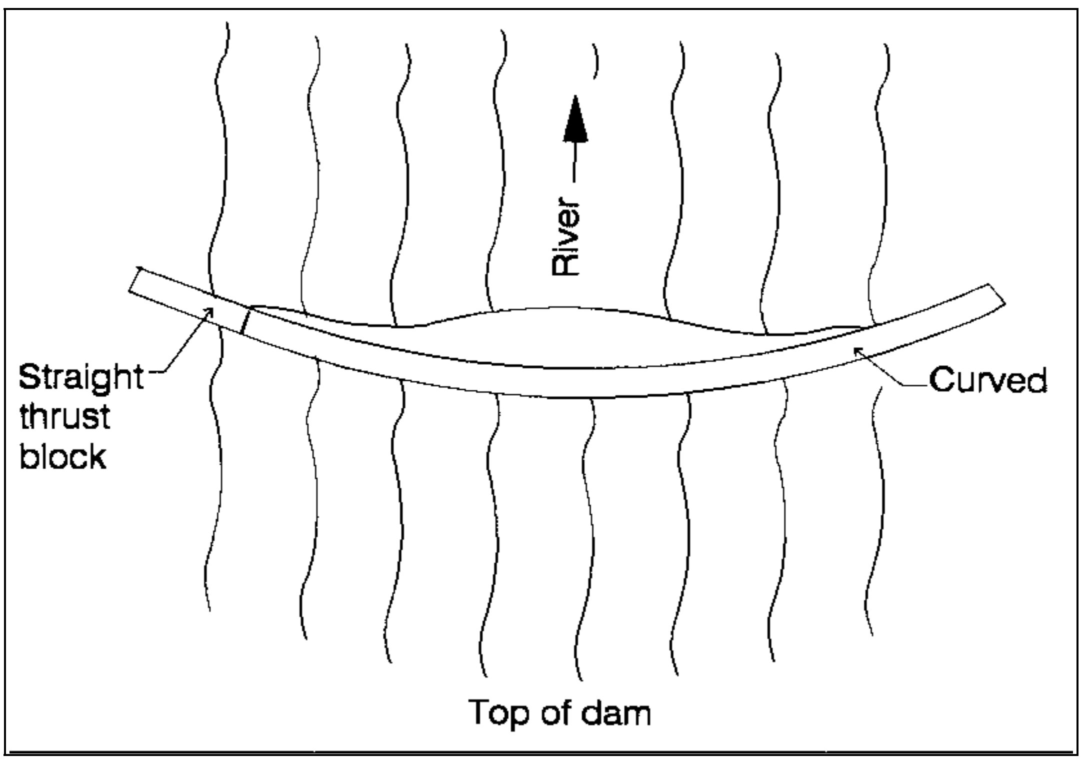


Figure 3-19. Schematic plan of straight and curved thrust blocks and water barrier