CHAPTER 13

CONSTRUCTION

13-1. Introduction. The design and analysis of any dam assumes that the construction will provide a suitable foundation (with minimal damage) and uniform quality of concrete. The design also depends on the construction to satisfy many of the design assumptions, including such items as the design closure temperature. The topics in this chapter will deal with the construction aspects of arch dams as they relate to the preparation of planning, design, and construction documents. Contract administration aspects are beyond the scope of this manual.

13-2. Diversion.

a. General. With arch dams, as with all concrete dams, flooding of the working area is not as serious an event as it is with embankment dams, since flooding should not cause serious damage to the completed portions of the dam and will not cause the works to be abandoned. For this reason, the diversion scheme can be designed for floods of relatively high frequencies corresponding to a 25-, 10-, or 5-year event. In addition, if sluices and low blocks are incorporated into the diversion scheme, the design flood frequency is reduced and more protection against flooding is added as the completed concrete elevation increases.

b. The Diversion Scheme. The diversion scheme will usually be a compromise between the cost of diversion and the amount of risk involved. The proper diversion plan should minimize serious potential flood damage to the construction site while also minimizing expense. The factors that the designer should consider in the study to determine the best diversion scheme include: streamflow characteristics; size and frequency of diversion flood; available regulation by existing upstream dams; available methods of diversion; and environmental concerns. Since streamflow characteristics, existing dams, and environmental concerns are project-specific items, they will not be addressed in this chapter.

(1) Size and Frequency of Diversion Flood. In selecting the flood to be used in any diversion scheme, it is not economically feasible to plan on diverting the largest flood that has ever occurred or may be expected to occur at the site. Consideration should be given to how long the work will be under construction (to determine the number of flood seasons which will be encountered), the cost of possible damage to work completed or still under construction if it is flooded, the delay to completion of the work, and the safety of workers and the downstream inhabitants caused by the diversion works. For concrete dams, the cost of damage to the project would be limited to loss of items such as formwork and stationary equipment. Delays to the construction would be primarily the cleanup of the completed work, possible replacement of damaged equipment, and possible resupply of construction materials (Figure 13-1). It is doubtful that there would be any part of the completed work that would need to be removed and reworked. The risk to workers and downstream residents should also be minimal since the normal loads on the dam are usually much higher than the diversion loads, and overtopping should not cause

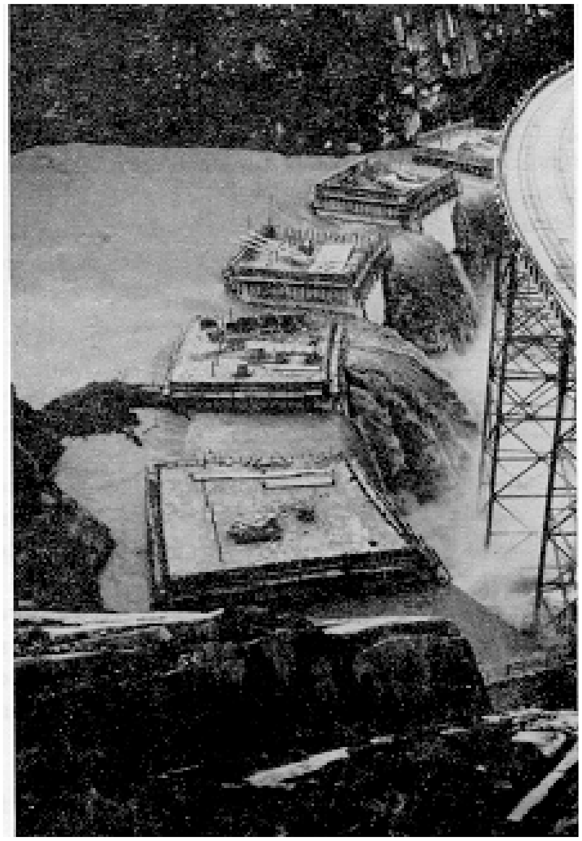


Figure 13-1. View from right abutment of partially complete Monticello Dam in California showing water flowing over low blocks (USBR)

serious undermining of the dam. And, as the concrete construction increases in elevation, the size of storm that the project can contain is substantially increased. Based on these considerations, it is not uncommon for the diversion scheme to be designed to initially handle a flood with a frequency corresponding to a 5- or 10-year event.

(2) Protection of the Diversion Works. The diversion scheme should be designed to either allow floating logs, ice and other debris to pass through the diversion works without jamming inside them and reducing their capacity, or prevent these items from entering the diversion works (International Commission on Large Dams 1986). Systems such as trash structures or log booms can be installed upstream of the construction site to provide protection by collecting floating debris.

(3) Other Considerations. If partial filling of the reservoir before completing the construction of the dam is being considered, then the diversion scheme must take into account the partial loss of flood storage. In addition,

partial filling will require that some method (such as gates, valves, etc.) be included in the diversion scheme so that the reservoir level can be controlled.

c. Methods of Diversion. Typical diversion schemes for arch dams include tunnels, flumes or conduits, sluices, low blocks, or a combination of any of these. Each of these will require some sort of cofferdam across the river upstream of the dam to dewater the construction site. A cofferdam may also be required downstream. The determination of which method or methods of diversion should be considered will rest on the site conditions.

(1) Tunnels and Culverts. Tunnels are the most common method of diversion used in very narrow valleys (Figure 13-2). The main advantage to using a diversion tunnel is that it eliminates some of the need for the staged construction required by other diversion methods. They also do not interfere with the foundation excavation or dam construction. The main disadvantage of a tunnel is that it is expensive, especially when a lining is required. As a result, when a tunnel is being evaluated as part of the diversion scheme, an unlined tunnel should be considered whenever water velocities and the rock strengths will allow. At sites where a deep crevice exists at the stream level and restitution concrete is already required to prevent excessive excavation, a culvert may be more economical than a tunnel (Figure 13-3). All tunnels and culverts will require a bulkhead scheme at their intakes to allow for closure and will need to be plugged with concrete once the dam is completed. The concrete plug will need to have a postcooling and grouting system (Figure 13-4).

(2) Channels and Flumes. Channels and flumes are used in conjunction with sluices and low blocks to pass the stream flows during the early construction phases. Channels and flumes should be considered in all but very narrow sites (Figures 13-5 and 13-6). Flumes work well where flows can be carried around the construction area or across low blocks. Channels will require that the construction be staged so that the dam can be constructed along one abutment while the river is being diverted along the base of the other abutment (Figure 13-6). Once the construction reaches sufficient height, the water is diverted through sluices in the completed monoliths (Figure 13-7). A similar situation applies for flumes. However, flumes can be used to pass the river through the construction site over completed portions of the dam. If the flume has adequate clearance, it is possible to perform limited work under the flume.

(3) Sluices and Low Blocks. Sluices and low blocks are used in conjunction with channels and flumes. Sluices and low blocks are used in the intermediate and later stages of construction when channels and flumes are no longer useful. Sluices become very economical if they can be incorporated into the appurtenant structures, such as part of the outlet works or power penstock (Figure 13-7). It is acceptable to design this type of diversion scheme so that the permanent outlet works or temporary low-level outlets handle smaller floods, with larger floods overtopping the low blocks (Figure 13-8). The low blocks are blocks which are purposely lagged behind the other blocks. As with the tunnel option, sluices not incorporated into the appurtenant structures will need to be closed off and concrete backfilled at the end of the construction (Figure 13-9).

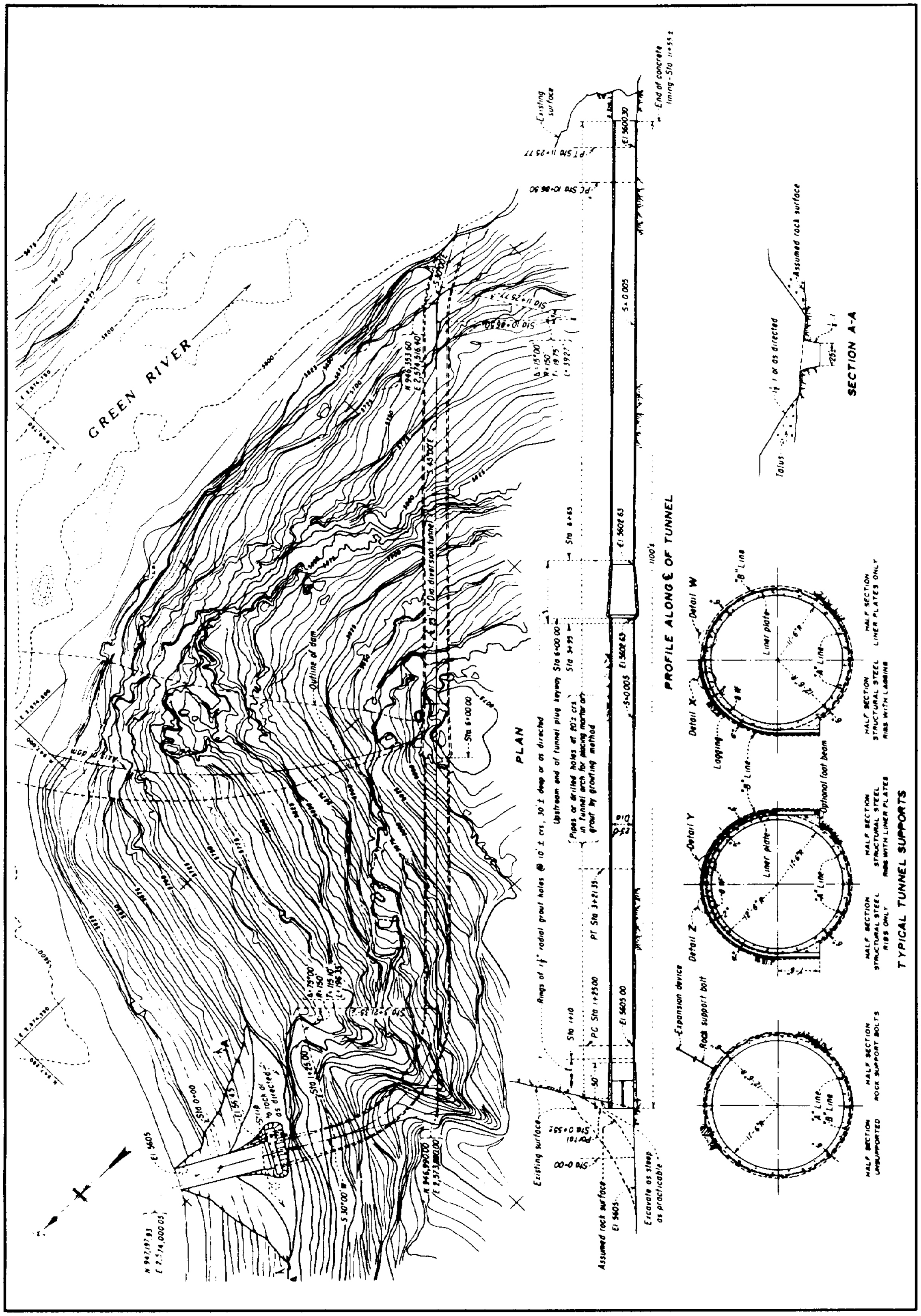


Figure 13-2. Diversion tunnel for Flaming Gorge Dam (USBR)

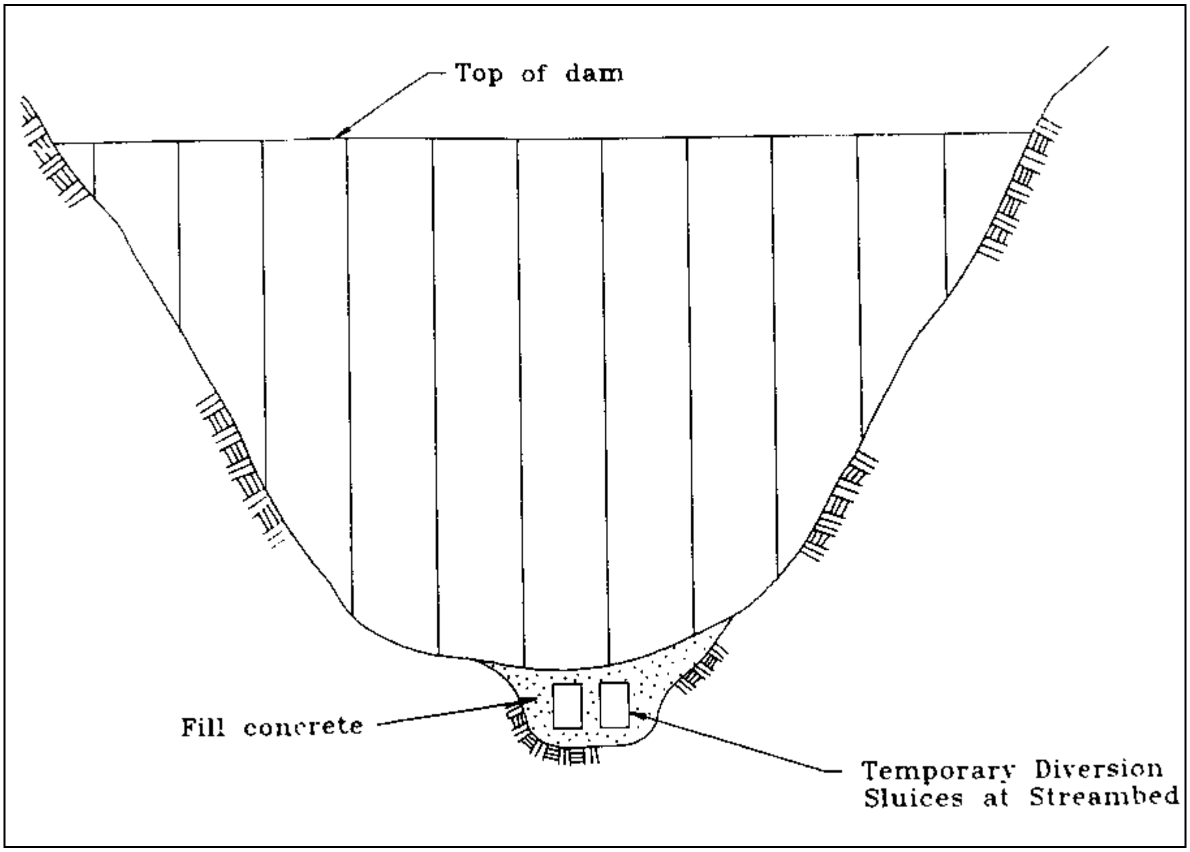


Figure 13-3. Diversion sluices through concrete pad at the base of a dam

13-3. Foundation Excavation. Excavation of the foundation for an arch dam will require that weak areas be removed to provide a firm foundation capable of withstanding the loads applied to it. Sharp breaks and irregularities in the excavation profile should be avoided (U.S. Committee on Large Dams 1988). Excavation should be performed in such manner that a relatively smooth foundation contact is obtained without excessive damage due to blasting. However, it is usually not necessary to over-excavate to produce a symmetrical site. A symmetrical site can be obtained by the use of restitutional concrete such as dental concrete, pads, thrust blocks, etc. Chapter 3 discusses restitutional concrete. Foundations that are subject to weathering and that will be left exposed for a period of time prior to concrete placement should be protected by leaving a sacrificial layer of the foundation material in place or by protecting the final foundation grade with shotcrete that would be removed prior to concrete placement.

13-4. Consolidation Grouting and Grout Curtain. The foundation grouting program should be the minimum required to consolidate the foundation and repair any damage done to the foundation during the excavation and to provide for seepage control. The final grouting plan must be adapted to suit field conditions at each site.

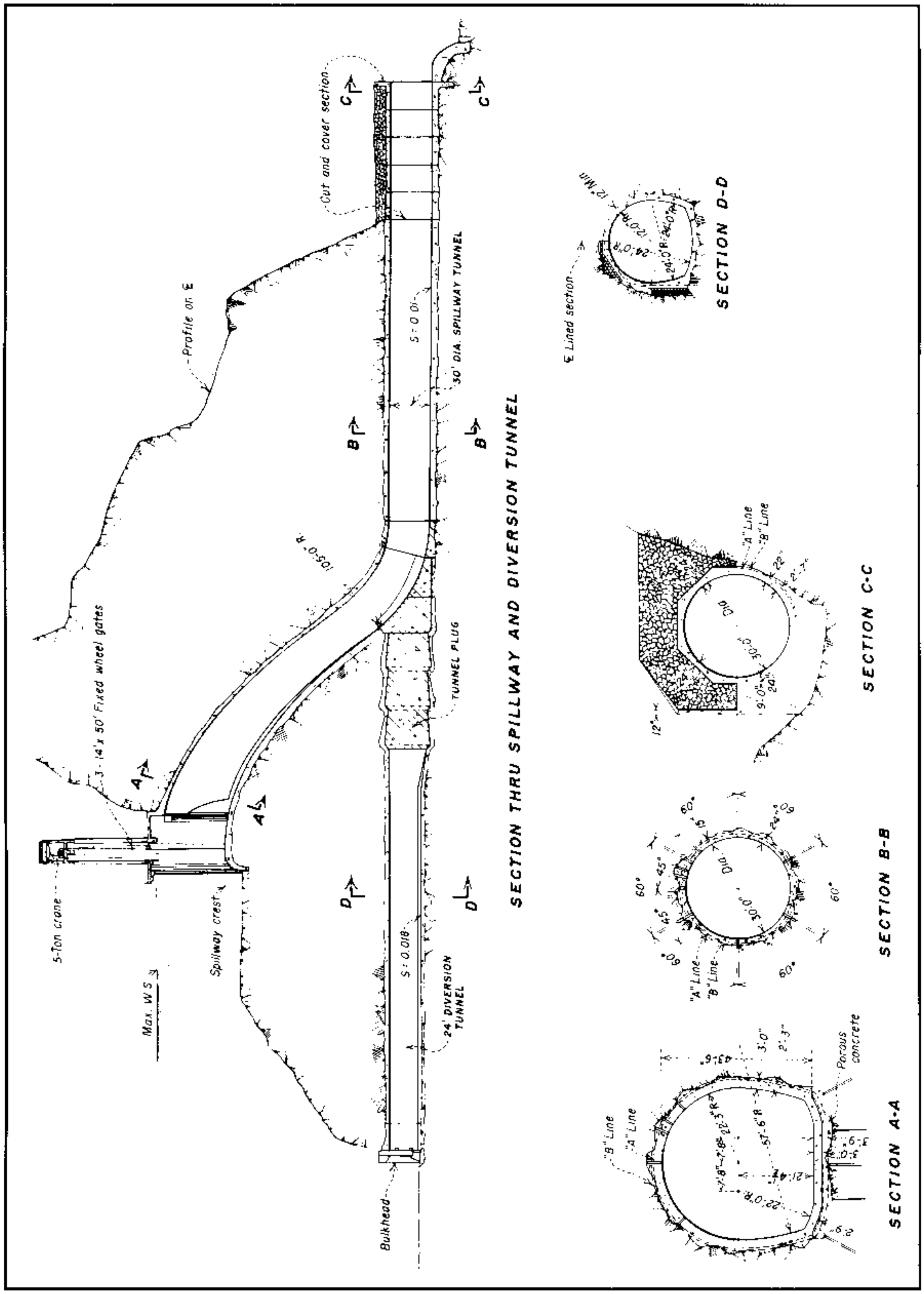


Figure 13-4. Typical diversion tunnel plug (USBR)

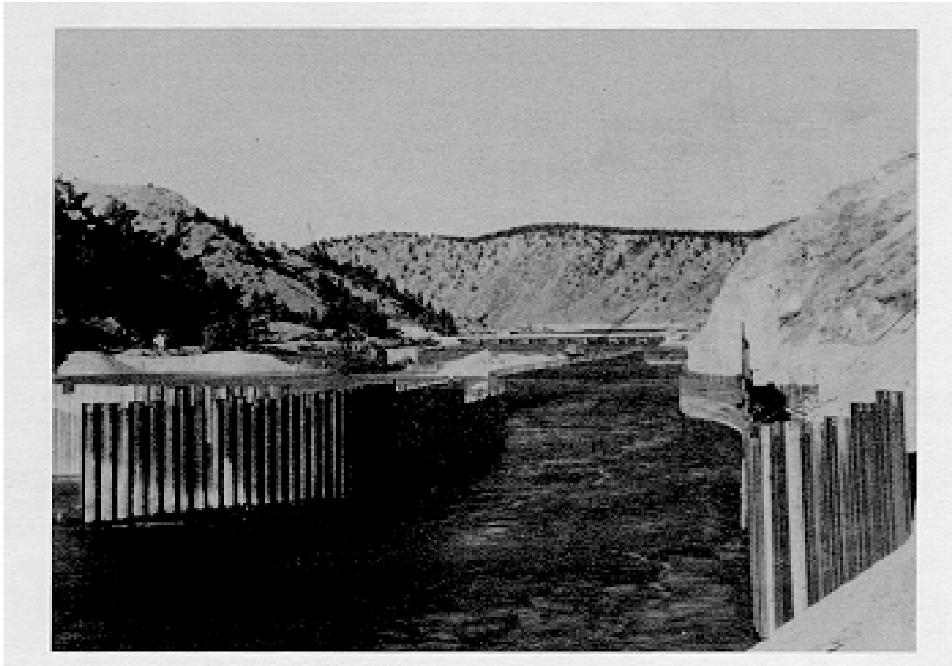


Figure 13-5. Complete diversion flume at Canyon Ferry damsite in use for first stage diversion (USBR)

a. Consolidation Grouting. Consolidation grouting consists of all grouting required to fill voids, fracture zones, and cracks at and slightly below the excavated foundation. Consolidation grouting is performed before any other grouting is done and is usually accomplished from the excavated surface using low pressures. In cases of very steep abutments, the grouting can be performed from the top of concrete placements to prevent "slabbing" of the rock. Holes should be drilled normal to the excavated surface, unless it is desired to intersect known faults, shears, fractures, joints, and cracks. Depths vary from 20 to 50 feet depending on the local conditions. A split-spacing process should be used to assure that all groutable voids, fracture zones, and cracks have been filled.

b. Grout Curtain. The purpose of a grout curtain is to control seepage. It is installed using higher pressures and grouting to a greater depth than the consolidation grouting. The depth of the grout curtain will depend on the foundation characteristics but will typically vary from 30 to 70 percent of the hydrostatic head. To permit the higher pressures, grout curtains are usually installed from the foundation gallery in the dam or from the top of concrete placements. If lower pressures in the upper portion can be used, the grout curtain can also be placed at foundation grade prior to concrete placement and supplemented by a short segment of grouting from the gallery to connect the dam and the previously installed curtain. Grout curtains can also be installed from adits or tunnels that extend into the abutments. The grout curtain should be positioned along the footprint of the dam in a region of zero or minimum tensile stress. It should extend into the foundation so that the base of the grout curtain is located at the vertical projection of the heel of the dam. To assist in the drilling operations, pipes are embedded in

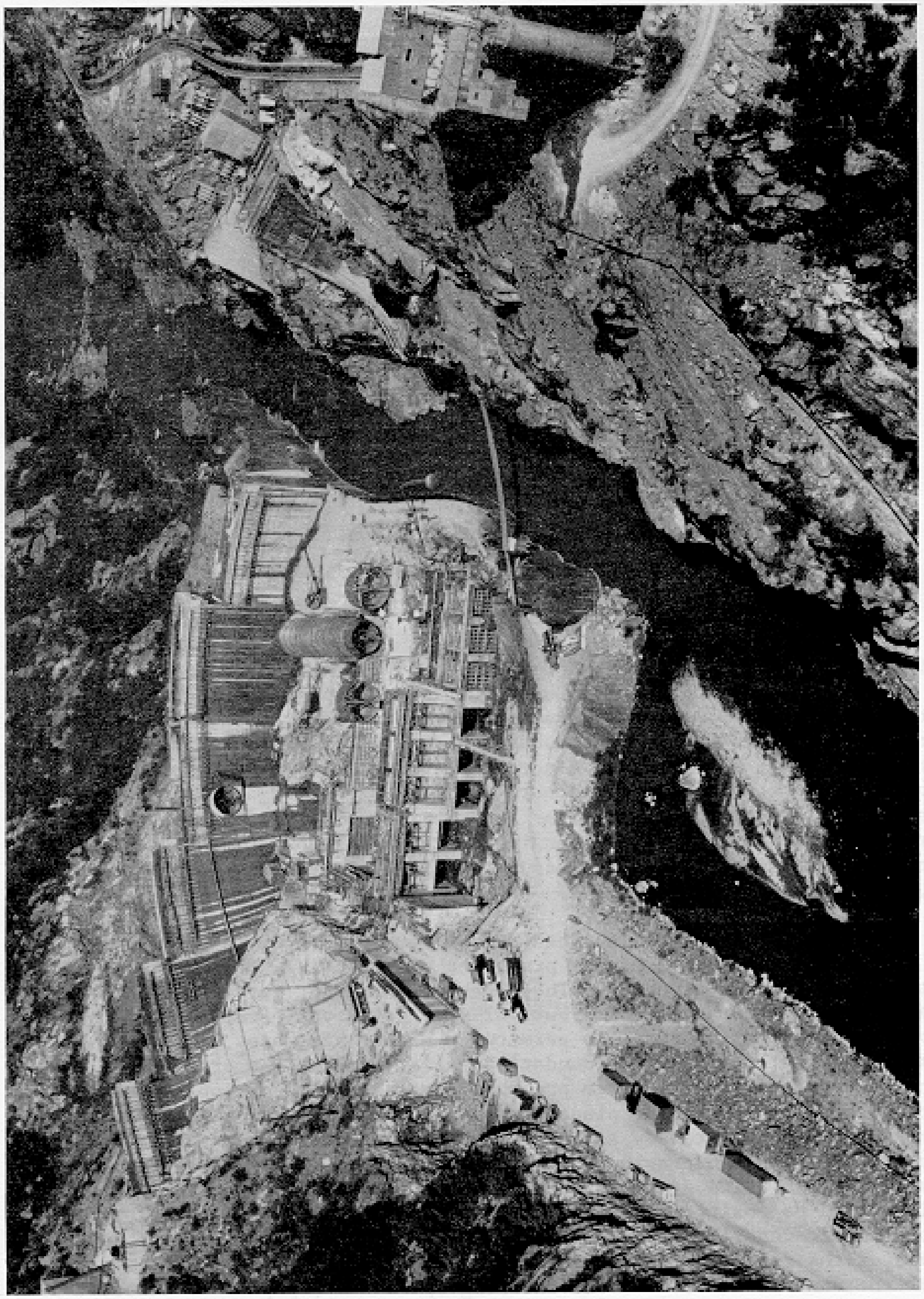


Figure 13-6. Channel used in the Phase I diversion for Smith Mountain Dam (photograph courtesy of Appalachian Power Company)

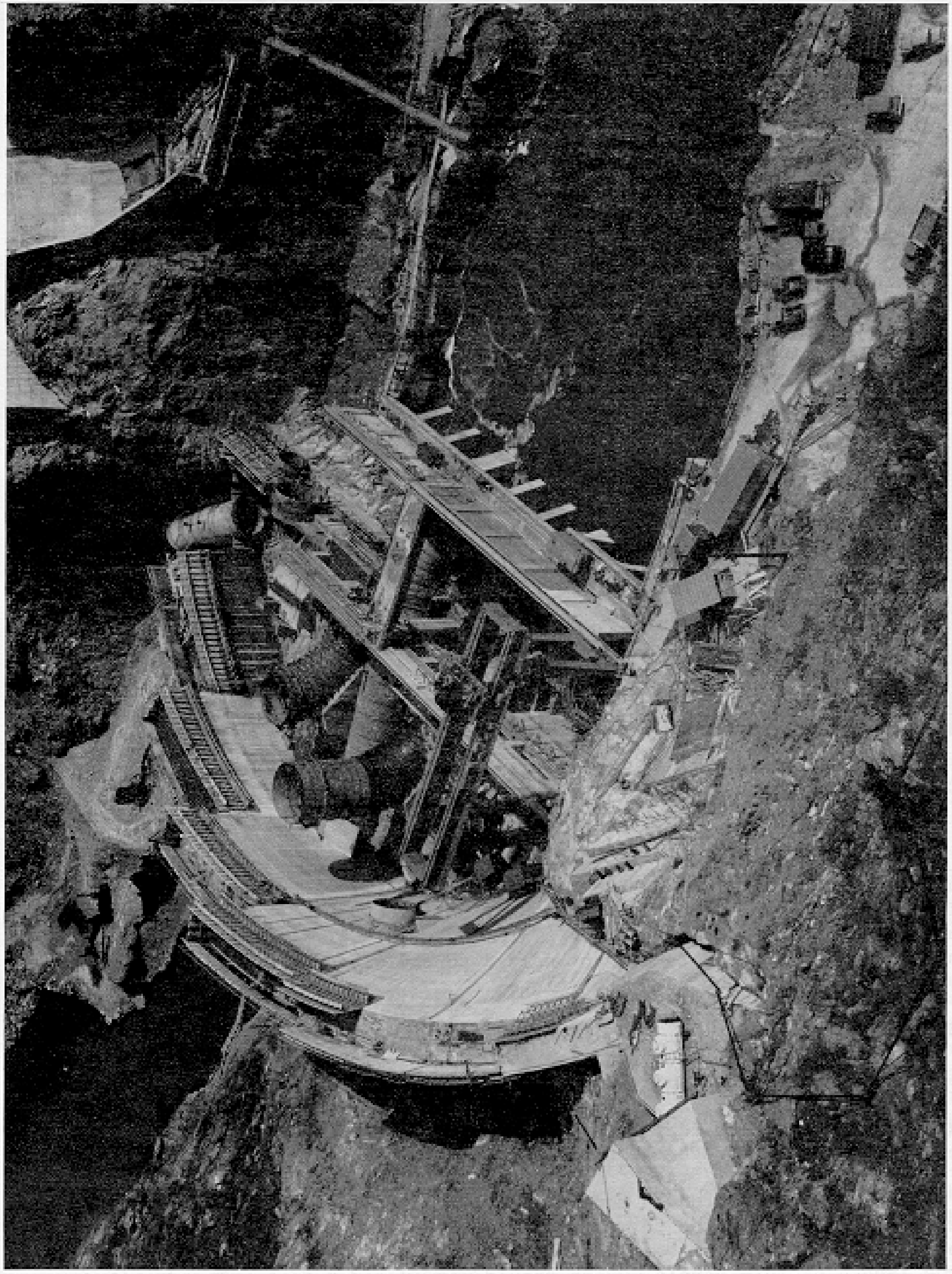


Figure 13-7. Sluice used in the Phase II diversion for Smith Mountain dam (photograph courtesy of Appalachian Power Company)

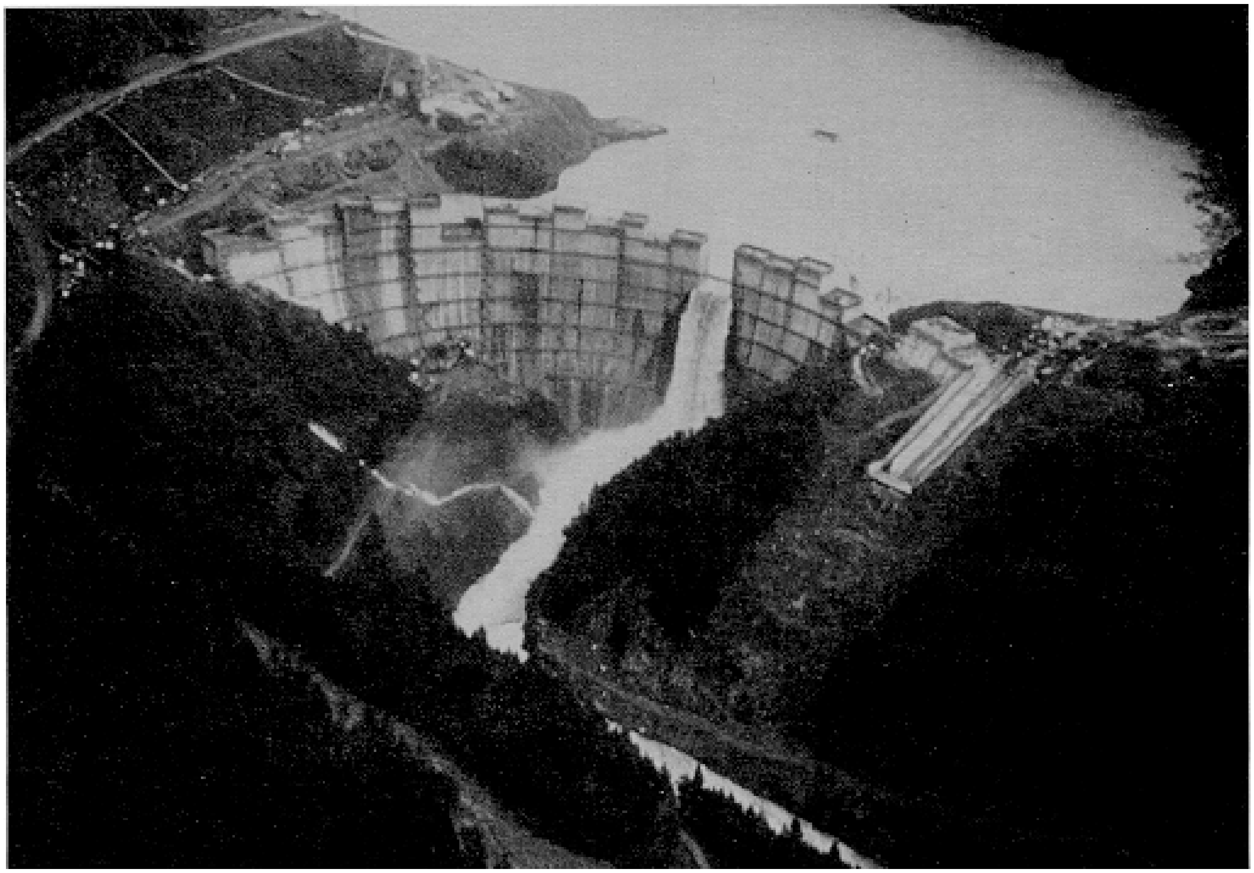


Figure 13-8. Aerial view of partially completed New Bullards Bar Dam in California showing water flowing over the low blocks (photograph courtesy of Yuba County Water Agency)

the concrete. Once the concrete placement has reached an elevation that the grouting pressure will not damage or lift the concrete, the grout holes are drilled through these pipes and into the foundation. Grout curtain operations should be performed before concrete placement starts or after the monolith joints have been grouted to prevent damage to the embedded grout stops and to prevent leakage into the monolith joints.

13-5. <u>Concrete Operations.</u> The concrete operations discussed in this section are the special concrete construction requirements for arch dams which are not covered in other chapters of this and other manuals. The topics of precooling and postcooling concrete are covered in Chapter 8. General concrete properties and mix design considerations are covered in Chapter 9. EM 1110-2-2000 discusses general concrete material investigations and specifications.

a. <u>Formwork.</u> Although modern arch dams are almost always curved in both plan and section, the forms used in constructing these dams are usually comprised of short, plane segments. The length of these segments correspond to the length of form panels, which should not exceed 8 feet. The detailed

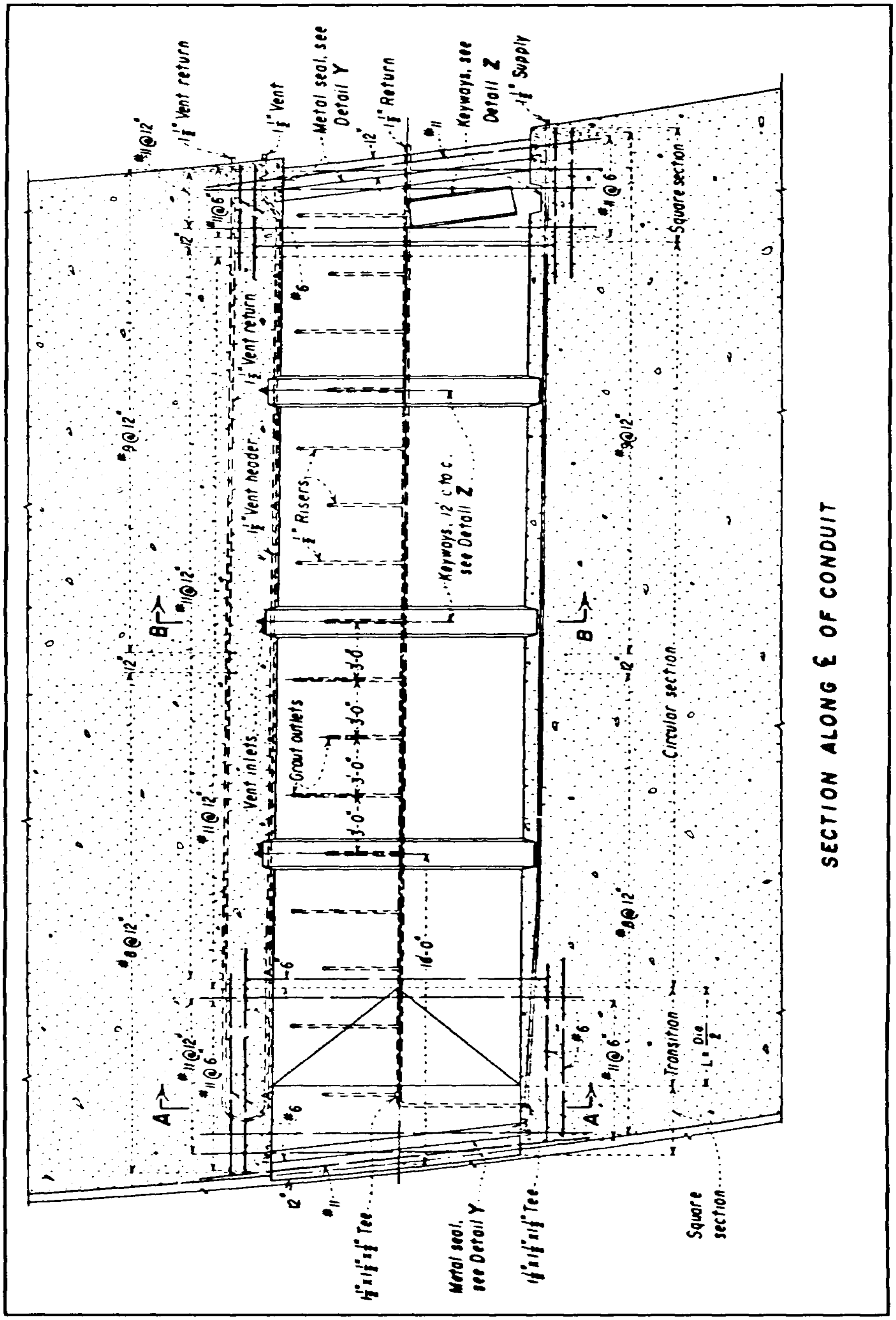


Figure 13-9. Diversion conduit through Morrow Point Dam (USBR) (Continued)

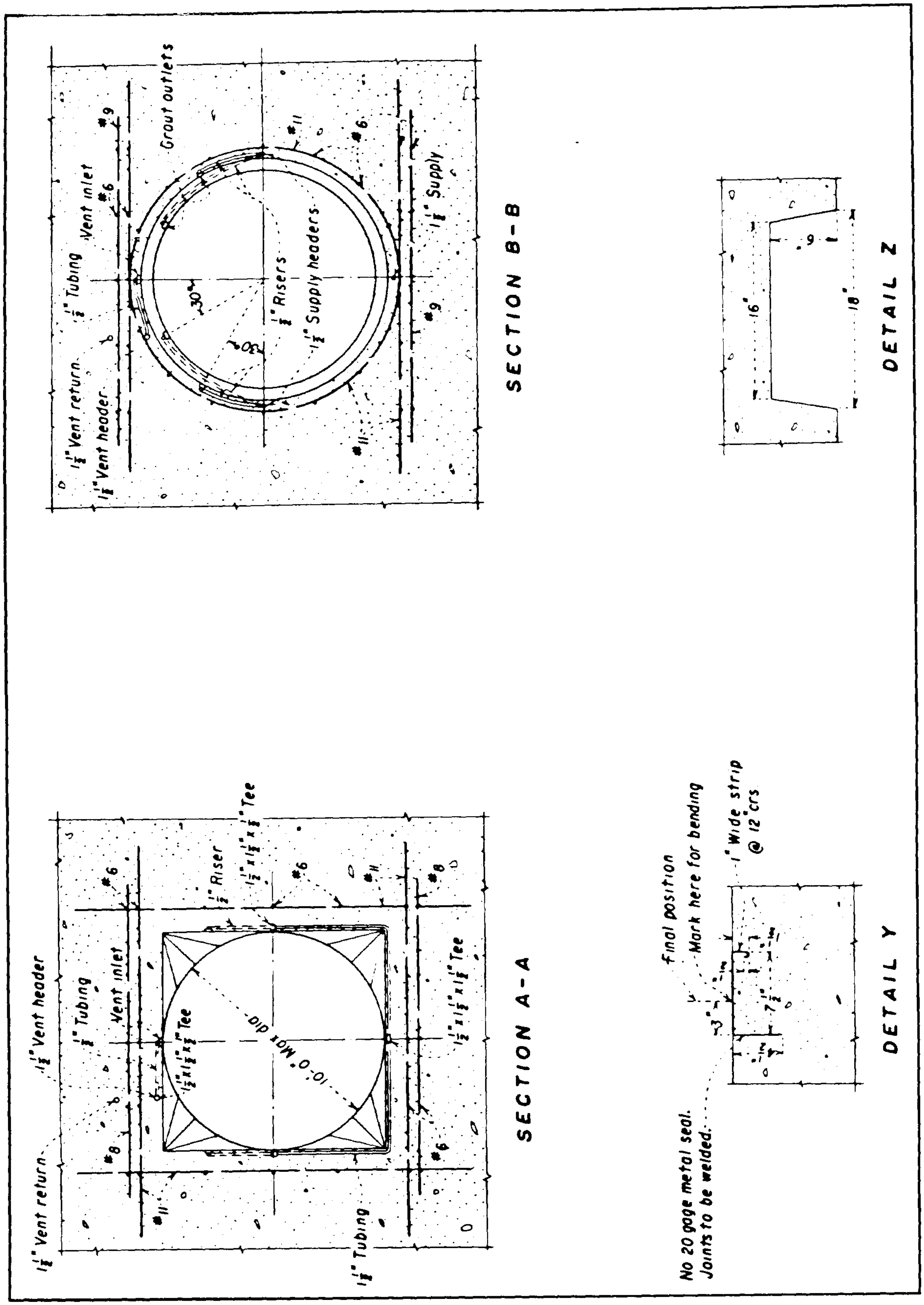


Figure 13-9. (Concluded)

positioning of the formwork is usually supplied to the contractor as part of the contract documents. The computer program Arch Dam Construction Program (ADCOP) has been developed to generate the information needed to establish the location of the formwork along the upstream and downstream faces of each lift. ADCOP is a PC based computer program which requires arch dam geometry information similar to the ADSAS program and generates data which will control layout of formwork for each monolith in the body of an arch dam. ADCOP generates contraction joints which are spiral in nature.

b. Height Differential. The maximum height differential between adjacent monoliths should be no more than 40 feet and no more than 70 to 100 feet between highest and lowest blocks in the dam. For dams with a pronounced overhang, limits should be placed on the placement of concrete with respect to ungrouted monoliths to avoid undesirable deflection and coincident tensile stresses.

c. Concrete Quality. The current trend in mass concrete construction is to minimize the use of cement by varying the concrete mixes used in different parts of the structure. This is usually done between the upstream and downstream faces and in areas of localized high stresses. For large dams, this practice can be very beneficial. For smaller dams, where the thicknesses are less than 30 feet, it may not be practical to vary the mix from the upstream to downstream faces. The benefits of adjusting the concrete mix for localized areas should be addressed, but the minimum requirements discussed in Chapter 9 should not be relaxed. Also, the effects of the differing cement contents created by these adjustments must be considered in the construction temperature studies discussed in Chapter 8.

d. Joint Cleanup. A good bond between horizontal construction joints is essential if cantilever tensile load transfer is to be achieved and leakage to the downstream face is to be minimized. Bond strength between lift lines can be almost as strong as the in-place concrete if the joints are properly prepared and the freshly placed concrete is well consolidated. Vertical contraction (monolith) joints that are to be grouted should be constructed so that no bond exists between the blocks in order that effective joint opening can be accomplished during the final cooling phase without cracking the mass concrete.

e. Exposed Joint Details. Joints should be chamfered at the exposed faces of the dam to give a desirable appearance and to minimize spalling.

13-6. Monolith Joints.

a. Spacing of Monolith Joints. The width of a monolith is the distance between monolith joints as measured along the axis of the dam. The determination of the monolith width will be part of the results of the closure temperature analysis discussed in Chapter 8. Once set, the monolith joint spacing should be constant throughout the dam if possible. In general, if the joints are to be grouted, monolith widths will be set at a value that allows for sufficient contraction to open the joints for grouting. However, there are limits to monolith widths. In recent construction, monolith widths have been commonly set at approximately 50 feet but with some structures having monoliths ranging from 30 to 80 feet. The USBR (1977) recommends that the ratio of the longer to shorter dimensions of a monolith be between 1 and 2.

Therefore, a dam with a base thickness of 30 feet could have a maximum monolith width of 60 feet. However, the thickness of the base of a dam will vary significantly as the dam progresses from the crown cantilever up the abutment contacts. Near the upper regions of the abutment contacts, the base thickness of the dam will drop to a value close to the thickness of the crest. If a dam has a base thickness of 30 feet at the crown cantilever and a crest thickness of only 10 feet, then the limit on the monolith width at the crown cantilever will be 60 feet while the limit near the ends of the dam would be 20 feet. Since monolith spacing must be uniform throughout the dam, the maximum limit can be set at the higher value determined for the crown cantilever, with the understanding that some cracking could be expected along the abutment contacts near the ends of the dam. In any case, the joint spacing should never exceed 80 feet.

b. Lift Heights. Lift heights are typically set at 5, 7.5, or 10 feet. This height should be uniform as the construction progresses from the base.

c. Water stops and Grout stops. The terms water stop and grout stop describe the same material used for different purposes. A water stop is used to prevent seepage from migrating through a joint, typically from the upstream face of the dam to the downstream face. A grout stop is used to confine the grout within a specified area of a joint. The materials used in water stops and grout stops are covered in EM 1110-2-2102. General layout for the water stops/grout stops for a grouted dam is shown in Figure 13-10. Figure 13-20 also shows a typical layout at the upstream face for ungrouted cases where a joint drain is added. Proper installation and protection of the water stop/grout stop during construction is as important as the shape and material.

d. Shear Keys. Shear keys are installed in monolith joints to provide shearing resistance between monoliths. During construction they also help maintain alignment of the blocks, and they may help individual blocks "bridge" weak zones within the foundation. Vertical shear keys, similar to those shown in Figure 13-11, will also increase the seepage path between the upstream and downstream faces. Other shapes of shear key, such as the dimple, waffle, etc., shown in Figures 13-12 and 13-13, have also been used. The main advantage in these other shaped keys is the use of standard forms and, in the case of the dimple shape, less interference with the grouting operations. However, these other shapes provide additional problems in concrete placement and are not as effective in extending the seepage path as are the vertical keys.

e. Vertical Versus Spiral Joints. Arch dams can be constructed with either vertical or spiral radial contraction joints. Vertical radial joints are created when all monolith joints, at each lift, are constructed on a radial line between the dam axis and the axis center on the line of centers (see Chapter 5 for definition of dam axis and axis center). Therefore, when looking at a plan view of a vertical joint, the joints created at each construction lift will fall on the same radial line. Spiral joints are created when the monolith joints, at each lift, are constructed on a radial line between the dam axis and with the intrados line of centers for that lift elevation. Therefore, when looking at a plan view of a spiral joint, each joint created at each construction lift will be slightly rotated about the dam axis. Spiral radial joints will also provide some keying of the monoliths, while vertical radial joints will not.

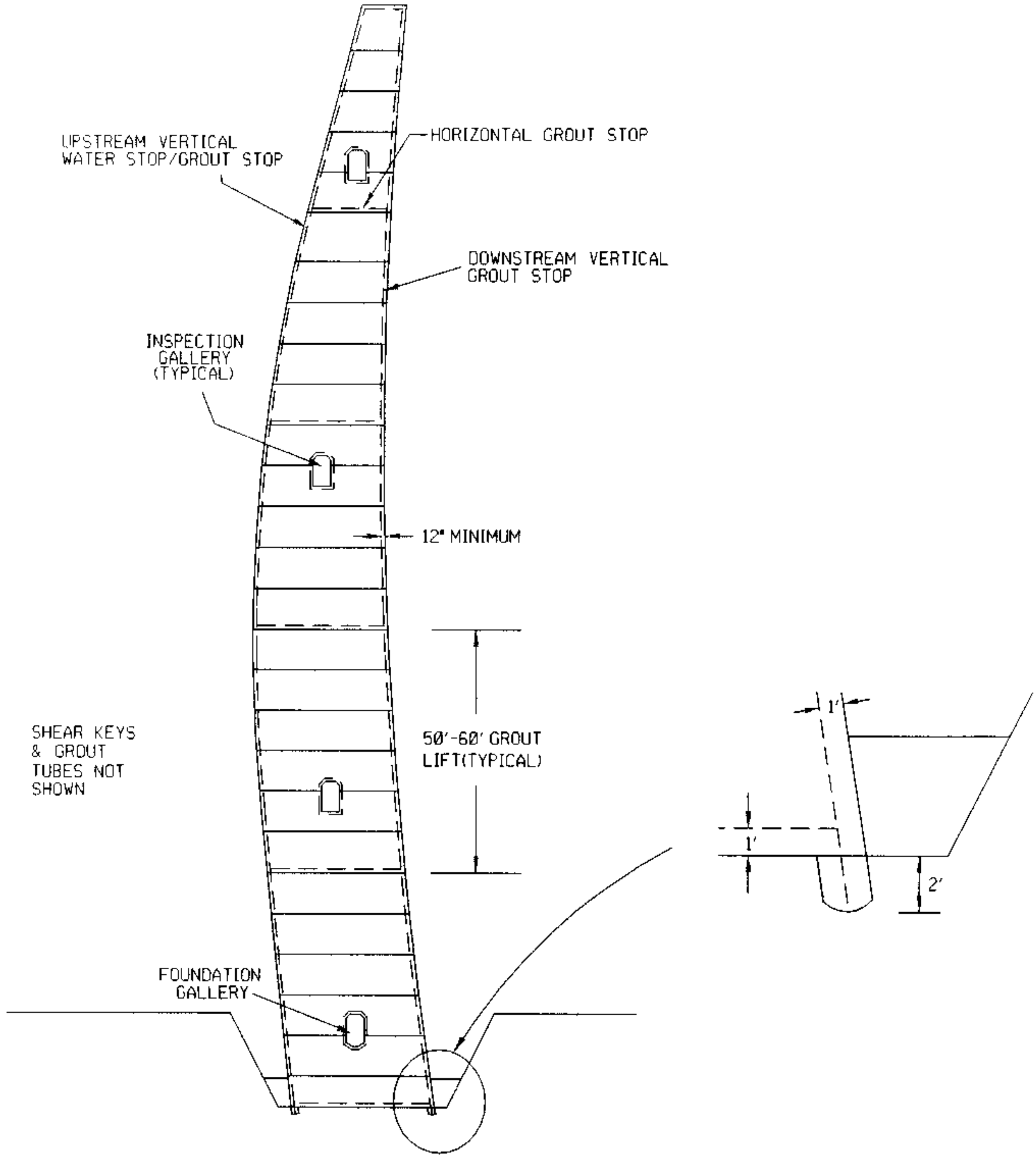


Figure 13-10. Water stop and grout stop details

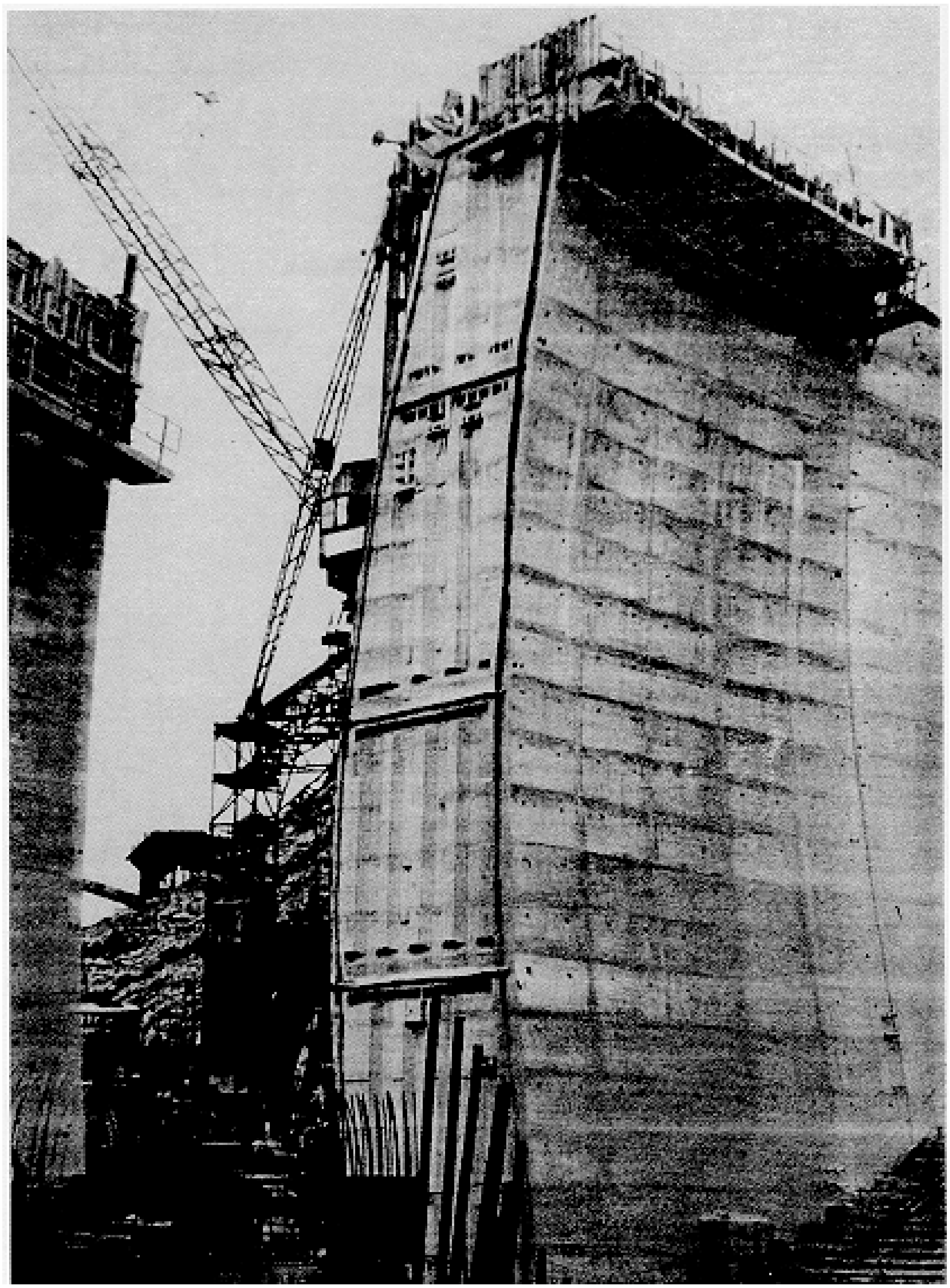
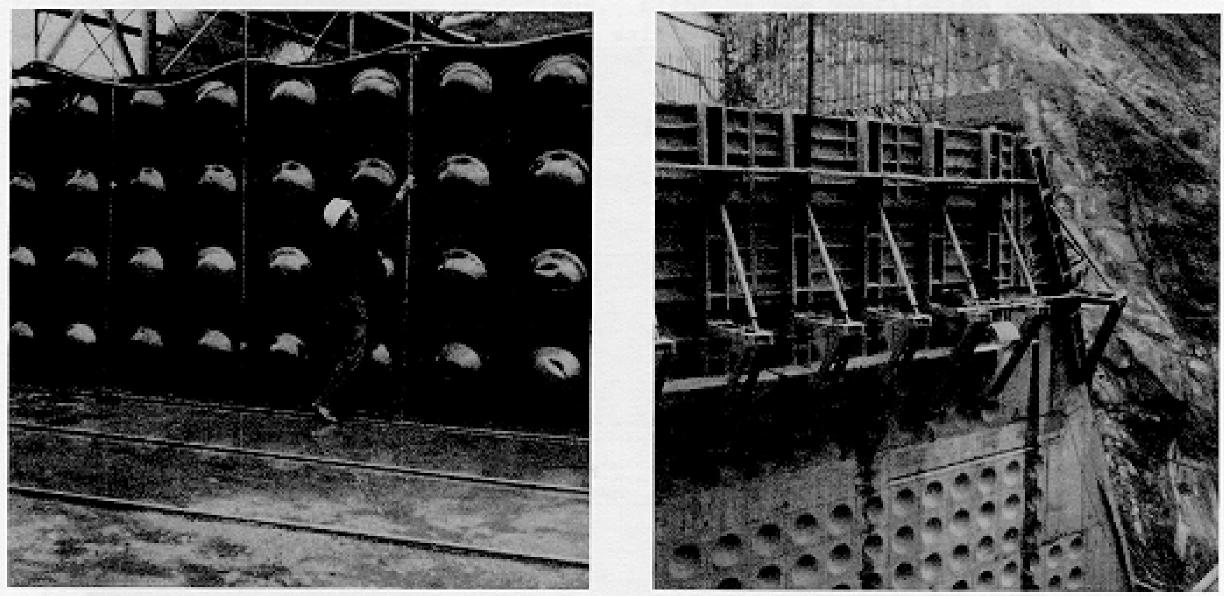


Figure 13-11. Vertical keys at monolith joints of Monar Dam, Scotland



a)

b)

Figure 13-12. Dimple shear keys

f. <u>Monolith Joint Grouting.</u> The purpose of grouting monolith joints is to provide a monolithic structure at a specified "closure temperature." To accomplish this, grout is injected into the joint by a means of embedded pipes similar to those shown in Figures 13-14 and 13-15. To ensure complete grouting of the joint prior to grout set, and to prevent excessive pressure on the seals and the blocks, grout lifts are usually limited to between 50 and 60 feet.

(1) <u>Joint Opening for Grouting.</u> The amount that a joint will open during the final cooling period will depend upon the spacing of the monolith joints, the thermal properties of the concrete, and the temperature drop during the final cooling period. The typical range of joint openings needed for grouting is 1/16 to 3/32 inch. With arch dams, where it is desirable to have a monolithic structure that will transfer compressive loads across the monolith joints, it is better to have an opening that will allow as thick a grout as practical to be placed. A grout mixture with a water-cement ratio of 0.66 (1 to 1 by volume) will usually require an opening on the higher side of the range given (Water Resources Commission 1981). In the initial design process, a required joint opening of 3/32 inch should be assumed.

(2) <u>Layout Details.</u> The supply loop at the base of the grout lift provides a means of delivering the grout to the riser pipes. Grout can be injected into one end of the looped pipe. The vertical risers extend from the supply loop at 6-foot intervals. Each riser contains outlets spaced 10 feet on centers, which are staggered to provide better grout coverage to the joint.

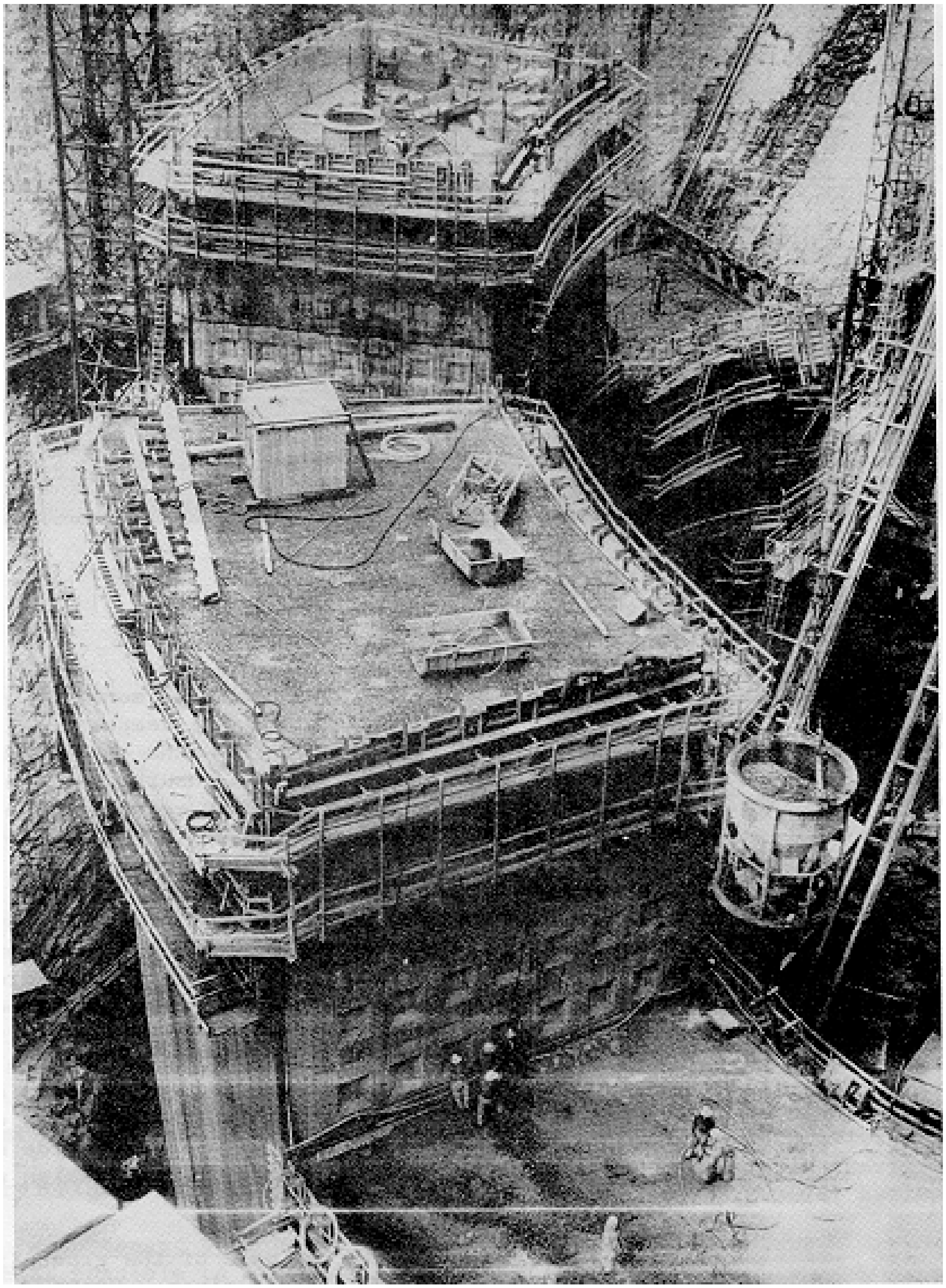


Figure 13-13. Waffle keys at the vertical monolith joints of Gordon Dam, Australia

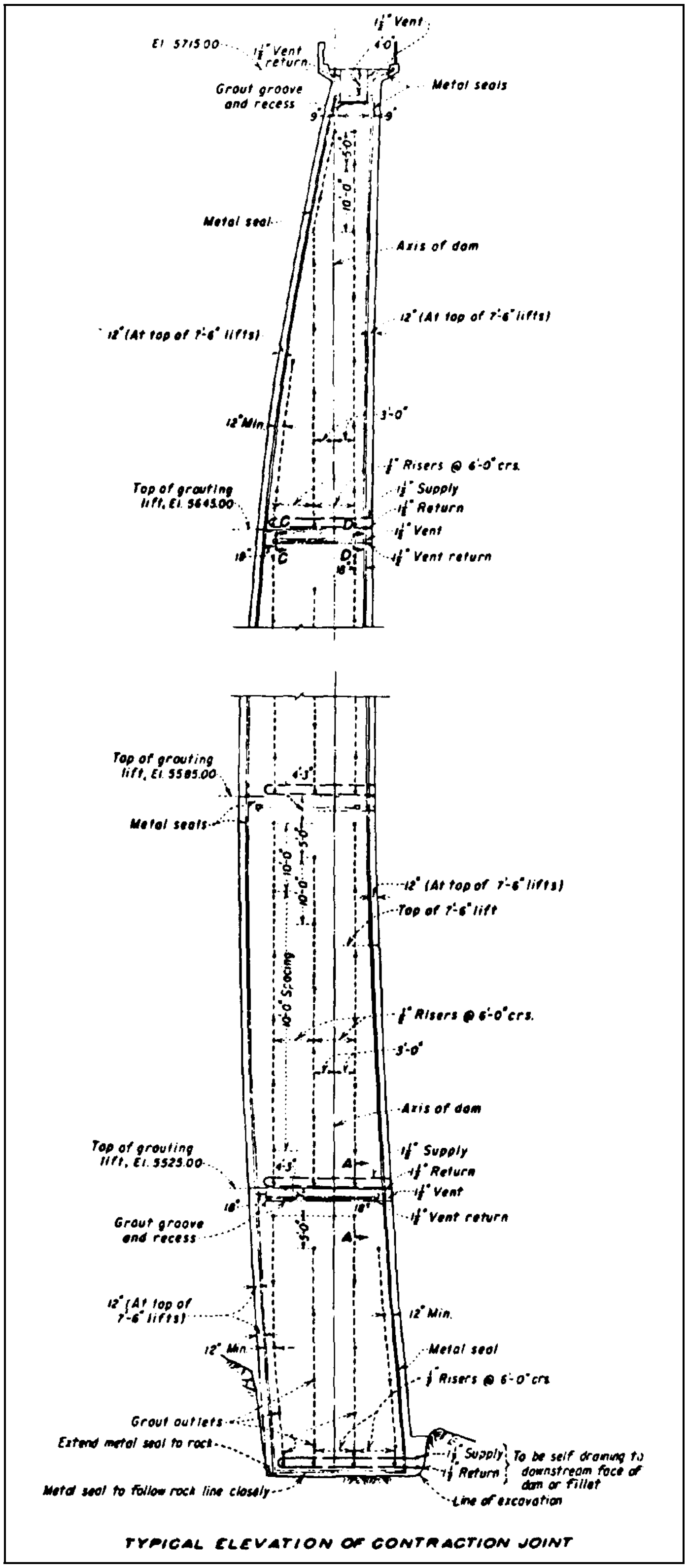
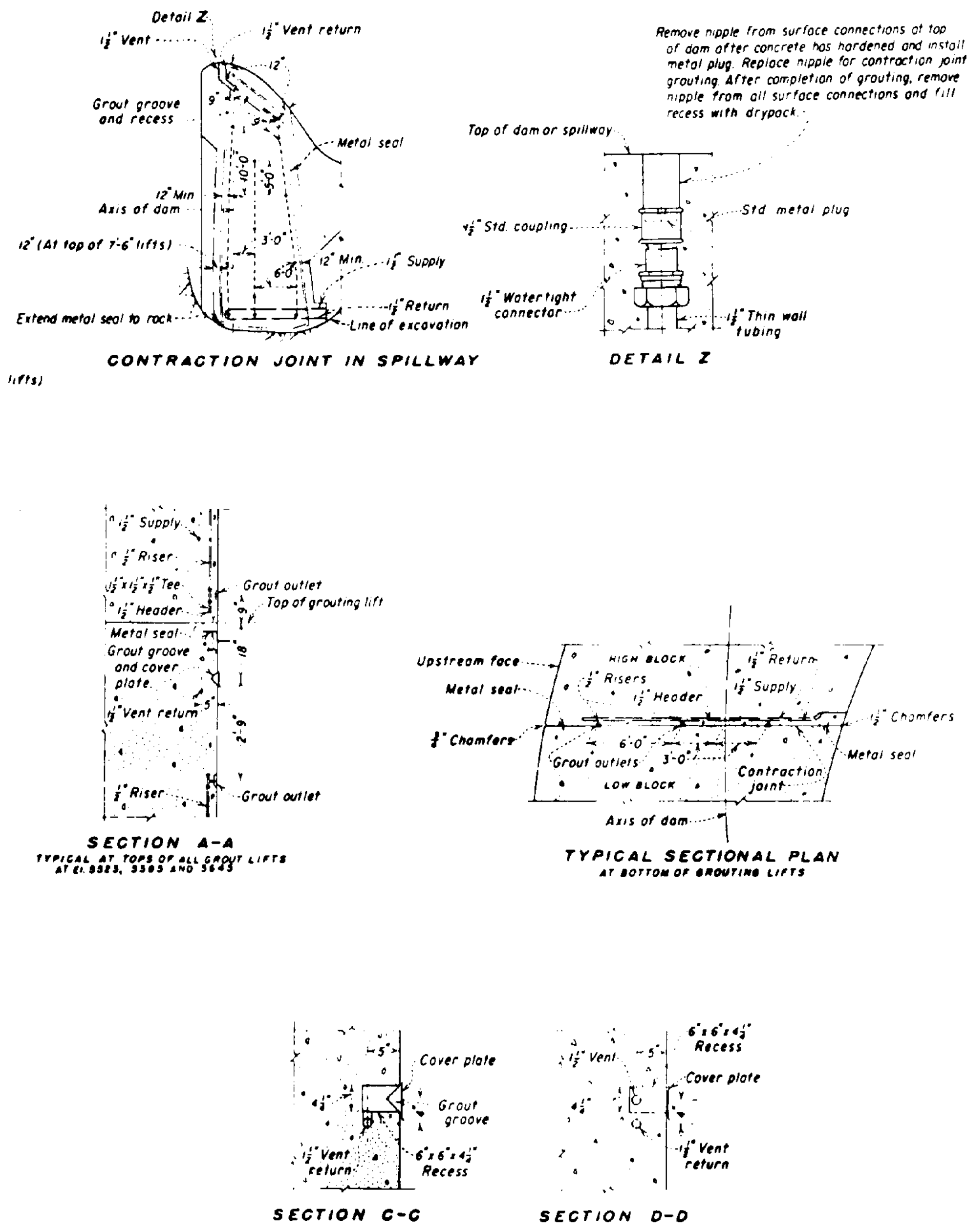


Figure 13-14. Contraction joint and grouting system for East Canyon Dam (USBR) (Continued)



NOTES

Metal seals shall be placed across all contraction joints as near bedrock as possible.
Place all tubing and grout outlets in the block with the higher elevation.
All header systems to be self draining.

Figure 13-14. (Concluded)

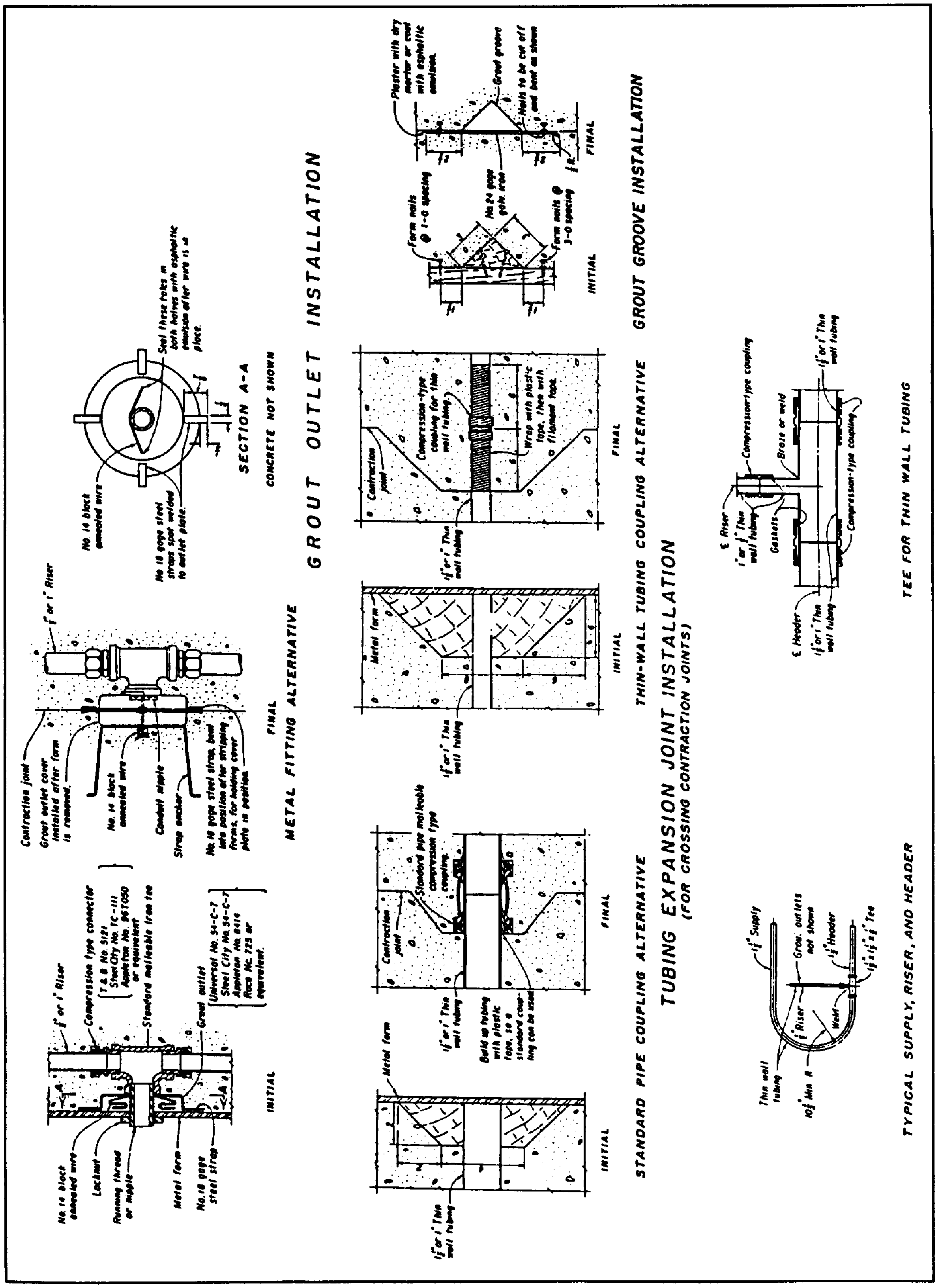


Figure 13-15. Example of grouting system details (USBR) (Continued)

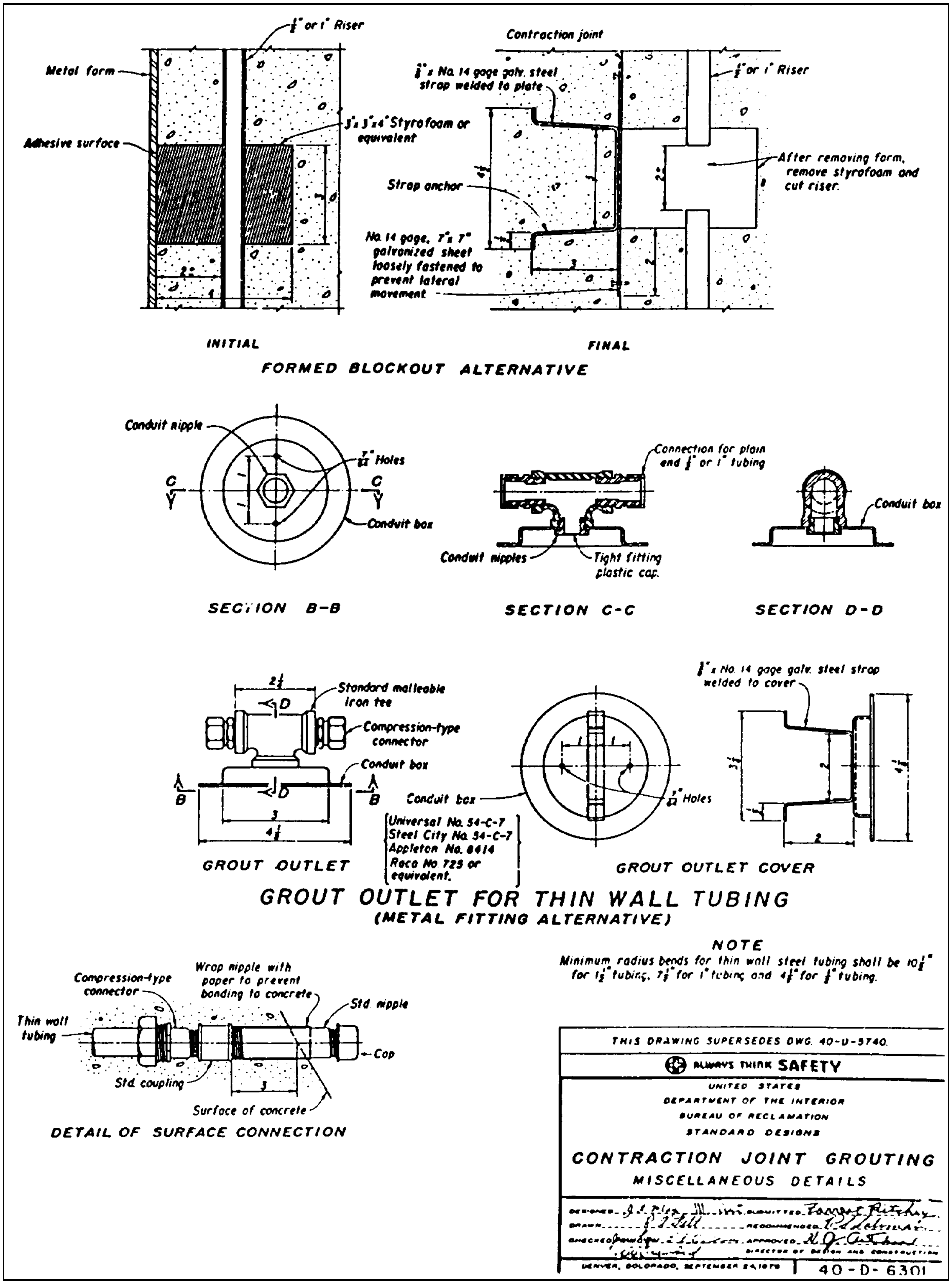


Figure 13-15. (Concluded)

The risers are discontinued near the vent loop (groove) provided at the top of the grout lift. Vent pipes are positioned at each end of the vent groove to permit air, water, and thin grout to escape in either direction. Normally, these systems are terminated at the downstream face. Under some conditions, they can be terminated in galleries. The ends of the pipes have nipples that can be removed after completion of the grouting and the remaining holes filled with dry pack. Typical grout outlet and vent details are shown in Figures 13-14 and 13-15.

(3) Preparation for Grouting. Prior to grouting, the system is tested to assure that obstructions do not exist. The monolith joint is then cleaned with air and water under pressure. The joint is filled with water for a period of 24 hours. The water is drained from the joint to be grouted. Joints of two or more ungrouted joints on either side are filled with water, but not pressurized. Once the grout reaches the top of the grout lift, the lift above is filled with water to protect the upper grout stop. Immediately after a grouting operation is completed, the water is drained from the joints in the lift above. Water in the adjacent ungrouted joints should remain in place for at least 6 hours after the grouting operation is completed.

(4) Grout Mix. The grout should consist of the thickest mix that will enter the joint, fill all of the small voids, and travel to the vent. Grout mixes usually vary from water-cement ratios of 2 to 1 by volume (1.33 by weight) at the start of the grouting operation to thicker mixes (1 to 1 by volume or 0.66 by weight) as the operation progresses. If the joints are sufficiently open to accept a thicker grout, then mixes with ratios of 0.70 to 1 by volume (0.46 by weight) should be used to finish the job.

(5) Grouting Operation. Grout is injected in the supply loop at the bottom of the grout lift so that grout first comes in contact with the riser farthest from the supply portal. This will allow for the most favorable expulsion of air, water, and diluted grout as the grouting operation progresses. Once the grout appears at the return end of the supply loop, the return end is closed and the grout is forced up the risers and into the joint. The grouting must proceed at a rate fast enough that the grout will not set before the entire joint is filled with a thick grout. However, the rate of grouting must also be slow enough to allow the grout to settle into the joint. When thick grout reaches one end of the vent loop at the top of the grout lift, grouting operations are stopped for a short time (5 to 10 minutes) to allow the grout to settle in the joint. After three to five repetitions of a showing of thick grout, the valves are closed and the supply pressure increased to the allowable limit (usually 30 to 50 psi) to force grout into all small openings of the joint and to force the excess water into the pores of the concrete, leaving a grout film of lower water-cement ratio and higher density in the joint. The limiting pressure is set at a value that will avoid excessive deflection in the block and joint opening in the grouted portions below the joint. The system is sealed off when no more grout can be forced into the joint as the pressure is maintained.

13-7. Galleries and Adits.

a. General. Adits are near horizontal passageways that extend from the surface into the dam or foundation. Galleries are the internal passageways within the dam and foundation and can be horizontal, vertical, or sloped.

Chambers or vaults are created when galleries are enlarged to accommodate equipment. Galleries serve a variety of purposes. During construction, they can provide access to manifolds for the concrete postcooling and grouting operations. The foundation gallery also provides a work space for the installation of the grout and drainage curtains. During operation, galleries provide access for inspection and for collection of instrumentation data. They also provide a means to collect the drainage from the face and gutter drains and from the foundation drains. Galleries can also provide access to embedded equipment such as gates or valves. However, with all the benefits of galleries, there are also many problems. Galleries interfere with the construction operations and, therefore, increase the cost of construction. They provide areas of potential stress concentrations, and they may interfere with the proper performance of the dam. Therefore, galleries, as well as other openings in the dam, should be minimized as much as possible.

b. Location and Size. Typical galleries are 5 feet wide by 7.5 feet high. Figure 13-16 shows the most typical shapes of galleries currently being used. Foundation galleries are somewhat larger to allow for the drilling and grouting operations required for the grout and drainage curtains. Foundation galleries can be as large as 6 feet wide by 8.5 feet high. Personnel access galleries, which provide access only between various features within the dam, can be as small as 3 feet wide by 7 feet high. Spiral stairs should be 6 feet 3 inches in diameter to accommodate commercially available metal stairs.

c. Limitations of Dam Thickness. Galleries should not be put in areas where the thickness of the dam is less than five times the width of the gallery.

d. Reinforcement Requirements. Reinforcement around galleries is not recommended unless the gallery itself will produce localized high tensile stresses or if it is positioned in an area where the surrounding concrete is already in tension due to the other external loads being applied to it. Even under these conditions, reinforcement is only required if the cracking produced by these tensions is expected to propagate to the reservoir. Reinforcement will also be required in the larger chambers formed to accommodate equipment.

e. Layout Details (Figure 13-17). Gallery and adit floors should be set at the top of a placement lift for ease of construction. Galleries should be at a slope comfortable for walking. Ramps can be used for slopes up to 10 degrees without special precautions and up to 15 degrees if nonslip surfaces are provided. Stairs can be used for slopes up to 40 degrees. Spiral stairs or vertical ladders can be used in areas where slopes exceed these limits. Landings should be provided approximately every 12 vertical feet when spiral stairs or ladders are used. Landings should also be provided in stairways if at all possible. Handrails should be provided in all galleries where the slope is greater than 10 degrees. There should be a minimum of 5 feet between the floor of the foundation gallery and the rock interface. There should also be a minimum 5-foot spacing between a gallery or adit and the monolith joints and external faces. The preferable location of the galleries is near the center of the monolith to minimize its impact on the section modulus of the cantilever. As a minimum, galleries should be located away from the upstream face at a distance that corresponds to 5 percent of the hydrostatic head.

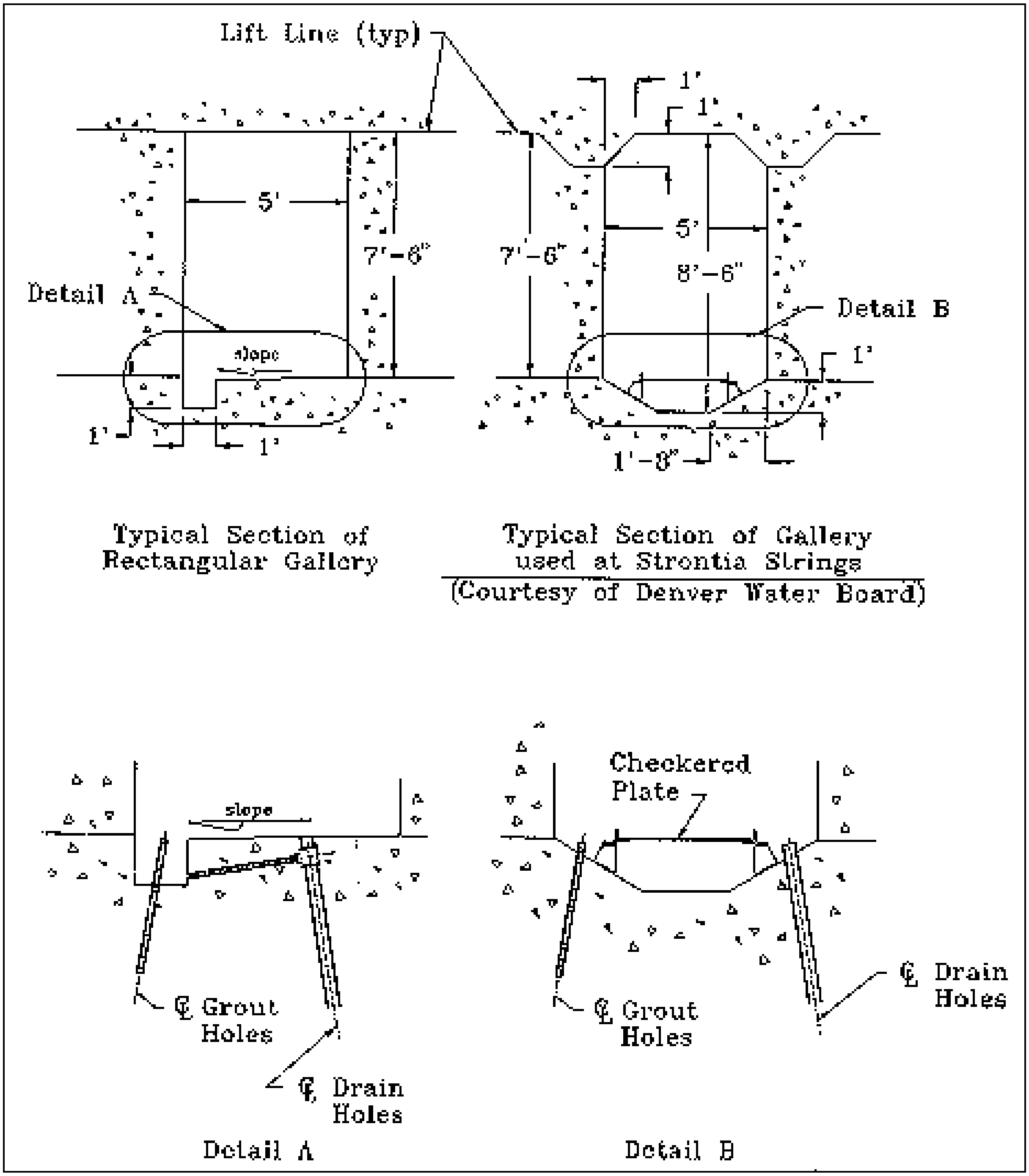


Figure 13-16. Typical gallery details

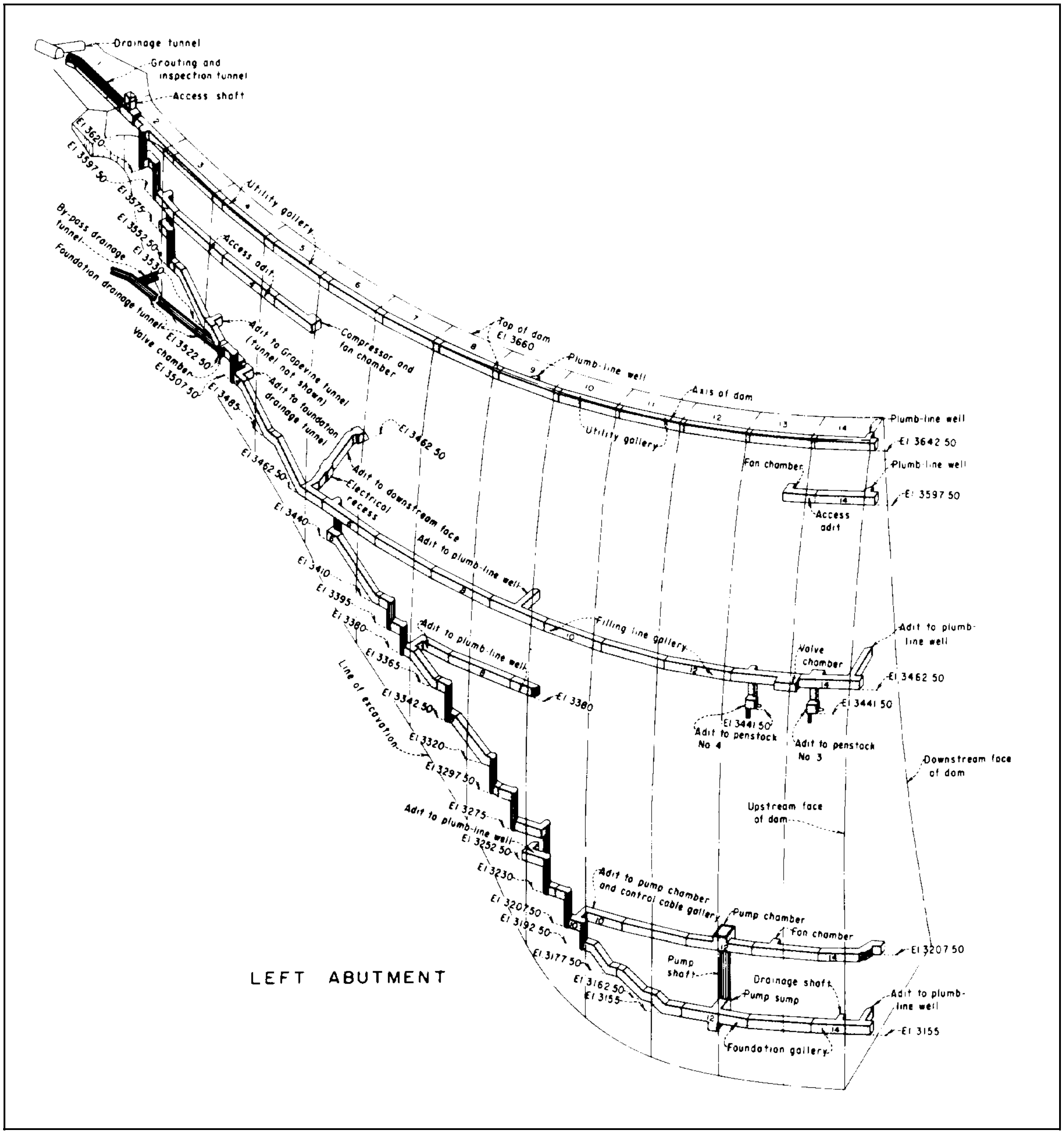


Figure 13-17. Left abutment gallery system for Yellowtail Dam (USBR)

f. Utilities. Water and air lines should be embedded in the concrete to help in future maintenance operations. Lighting and ventilation should also be provided for the convenience and safety of personnel working in the galleries. Telephones should be located in gate rooms or chambers within the dam, as well as scattered locations throughout the galleries, for use in emergencies and for convenience of operation and maintenance personnel.

13-8. Drains. Drains fall into two categories: foundation drains and embedded drains. Embedded drains include face drains, gutter drains, and joint drains. All arch dams should include provisions for foundation drains and for face and gutter drains. Joint drains are not recommended if the monolith joints are to be grouted because they can interfere with the grouting process. Providing water/grout stops on each side of the drain help alleviate that problem, but the addition of the drain and the grout stop reduces the available contact area between the grout and mass concrete and thereby reduces the area for load transfer between adjacent monoliths.

a. Foundation drains. Foundation drains provide a way to intercept the seepage that passes through and around the grout curtain and thereby prevents excessive hydrostatic pressures from building up within the foundation and at the dam/foundation contact. The depth of the foundation drains will vary depending on the foundation conditions but typically ranges from 20 to 40 percent of the reservoir depth and from 35 to 75 percent of the depth of the grout curtain. Holes are usually 3 inches in diameter and are spaced on 10-foot centers. Holes should not be drilled until after all foundation grouting in the area has been completed. Foundation drains are typically drilled from the foundation gallery, but if no foundation gallery is provided, they can be drilled from the downstream face. Foundation drains can also be installed in adits or tunnels that extend into the abutments.

b. Face Drains. Face drains are installed to intercept seepage along the lift lines or through the concrete. They help minimize hydrostatic pressure within dam as well as staining on the downstream face. Face drains extend from the crest of the dam to the foundation gallery. If there is no foundation gallery, then the drains are extended to the downstream face and connected to a drain pipe in the downstream fillet. They should be 5 or 6 inches in diameter and located 5 to 10 feet from upstream face. If the crest of the dam is thin, the diameter of the drains can be reduced and/or the distance from the upstream face can be reduced as they approach the crest. Face drains should be evenly spaced along the face at approximately 10 feet on centers (Figure 13-18).

c. Gutter Drains. Gutter drains are drains that connect the gutters of the individual galleries to provide a means of transporting seepage collected in the upper galleries to the foundation gallery and eventually to the downstream face or to a sump. These drains are 8-inch-diameter pipes and extend from the drainage gutter in one gallery to the wall or drainage gutter in the next lower gallery. These drains are located in approximately every fourth monolith (Figure 13-19).

d. Joint Drains. As noted earlier, joint drains are not normally installed in arch dams because of the joint grouting operations. However, if the monolith joints are not to be grouted, or if drains are required in grouted joints and can effectively be installed, then a 5- or 6-inch drain

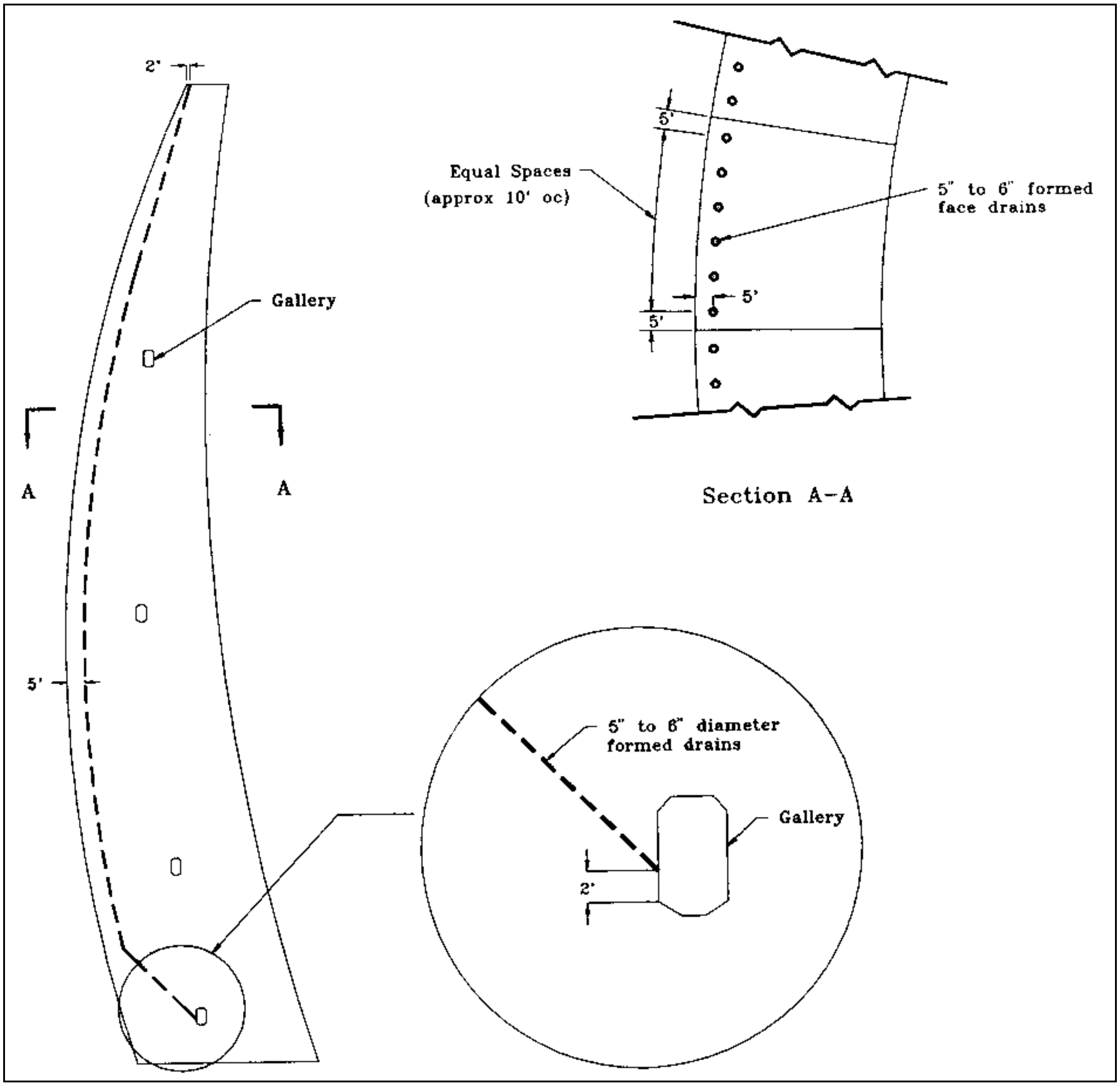


Figure 13-18. Details of face drains

similar to the face drains should be used. The drain should extend from the crest of the dam to the foundation and should be connected to the foundation gallery (Figure 13-20).

13-9. Appurtenant Structures. The appurtenant structures should be kept as simple as possible to minimize interference with the mass concrete construction. Outlet works should be limited to as few monoliths as possible. Conduits should be aligned horizontally through the dam and should be restricted to a single construction lift. Vertical sections of the conduits can be placed outside the main body of the dam.

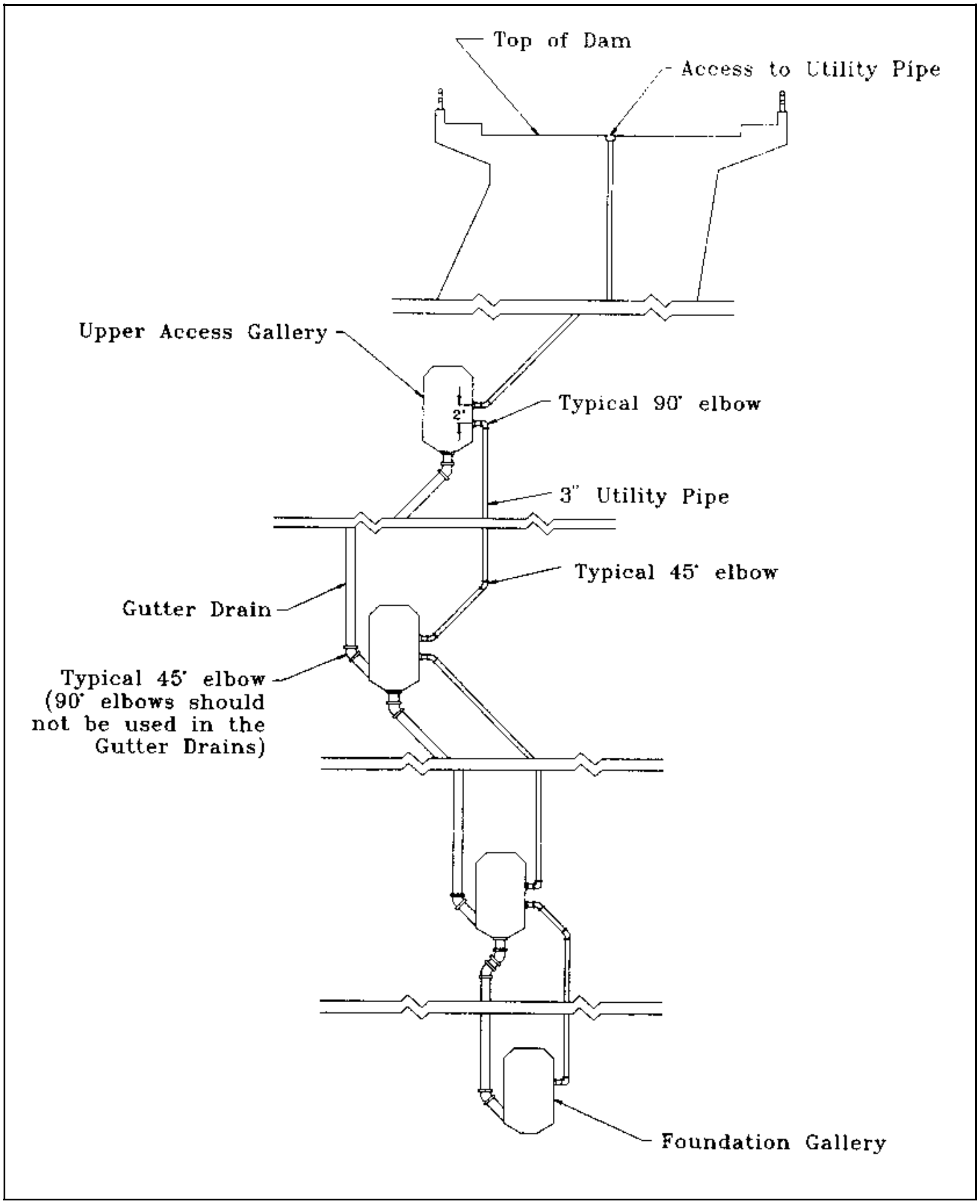


Figure 13-19. Details of gutter drains and utility piping

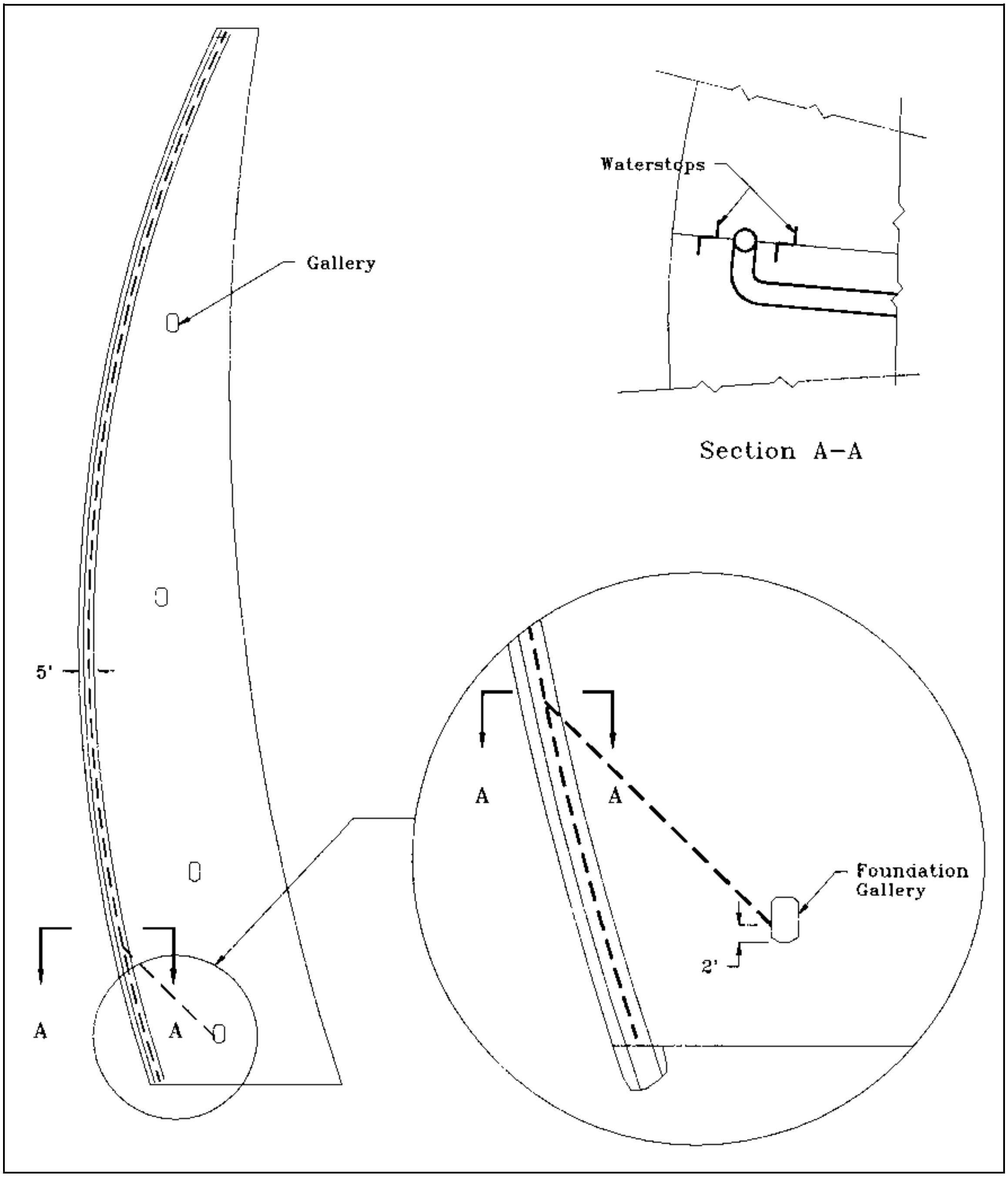


Figure 13-20. Details of joint drains