CHAPTER 7
APPLICATION TO WATER RETENTION STRUCTURES

7-1. Concrete Dams.

a. Preparation for Grouting.

(1) Excavation for concrete structure foundations should be closely controlled to prevent damage to the rock. Final grade should be approached with great care to prevent damage by blasting and to minimize the necessity for foundation treatment. If consolidation grouting is required, it should be performed prior to final cleanup of the foundation. The cleaning and grouting of existing exploratory holes should also be performed at this time. The rock surfaces should be cleaned sufficiently so that grout surface leaks can be found and caulked.

(2) Under some conditions where open fractures exist in the foundation, pipe embedded in the fracture prior to concrete placement, and running to the gallery for future grouting, may be desirable. At least two pipes should usually be set, so that one will provide a return and serve as a telltale during grout placement. Large solution cavities should be cleaned and either backfilled with concrete, or with gravel and then grouted. Additional pipe should be run to the gallery for future grouting. Just prior to concrete placement the grout pipe and drain pipe should be set and run to the gallery gutter form.

(3) Exposed final rock surfaces that are subject to deterioration should be protected within an established exposure time limit.

b. Grouting Patterns. A typical profile and section of a main grout curtain under a sizable concrete dam is shown in figure 7-1. The notes on this figure relative to the size and the spacing of holes and to the order of operations will not apply to grouting under all concrete dams, but are generally representative of the more common practices. The extent of treatment may vary from no grouting to a multiple-line curtain and to area grouting treatment (B-holes in fig. 7-1) depending upon the particular project conditions. The curtain produced by drilling and grouting the C-holes in figure 7-1 prevents the grout from traveling too far upstream from the dam and greatly reduces the amount of seepage flow in horizontally fractured formations. Grouting under power plants and navigation lock structures is often done to effect a reduction in uplift or to facilitate unwatering operations. A grout curtain supplemented by a drainage system will normally suffice in both cases.

c. Schedule for Grouting Operations. The construction stage at which to perform foundation grouting is a matter of judgment and depends on the purpose of the grouting to be done, the foundation conditions, and the type of structure. Area grouting is generally done before concrete placement. On the other hand, curtain grouting or grouting for leakage or uplift control is

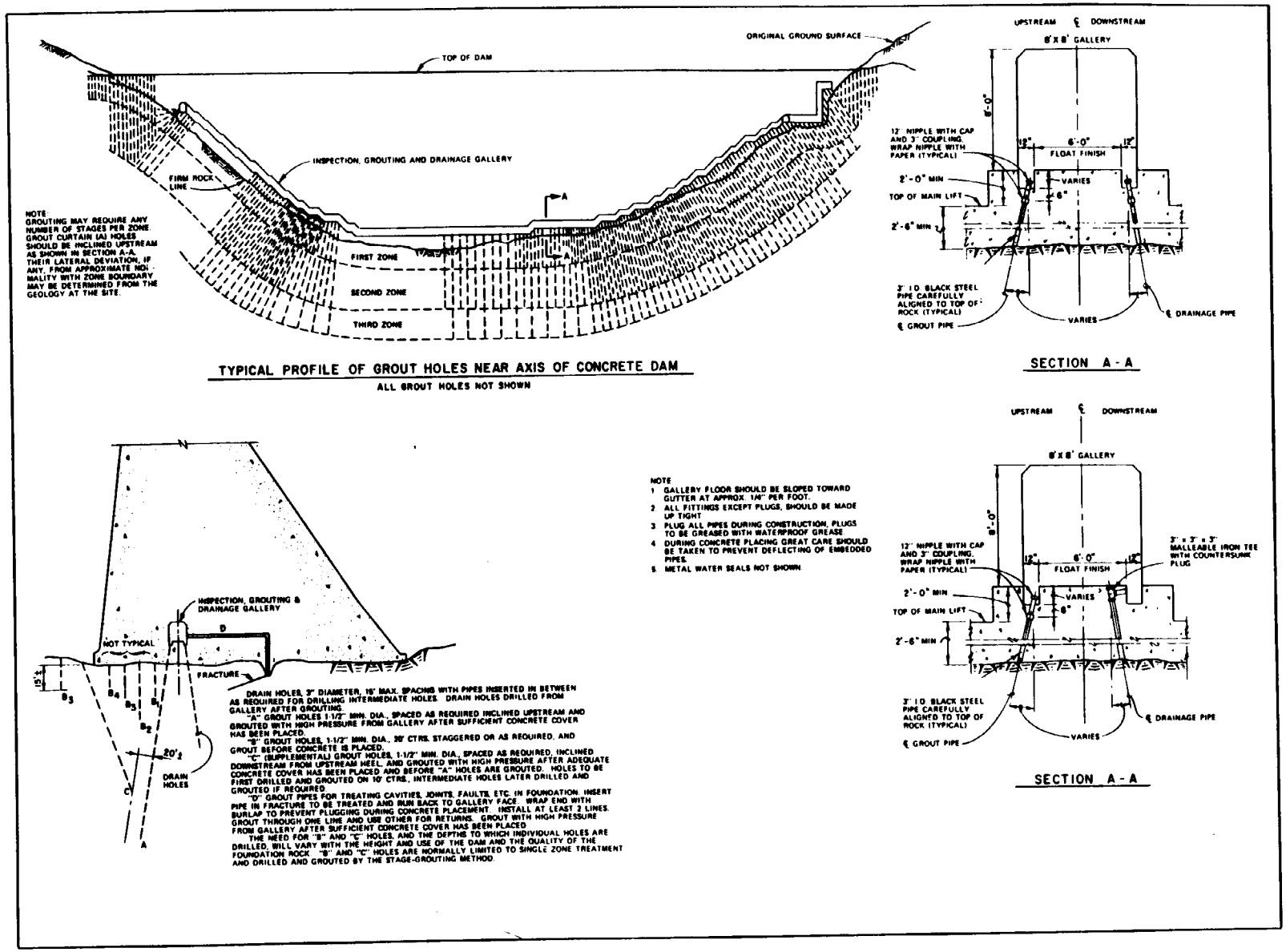

Figure 7-1. Multiple line cutoff

commonly done after concrete has been placed to a considerable height or even after the structure has been completed. This is especially true for high structures where the superimposed load allows the use of grouting pressures considerably higher than those that could be used before concrete placement. The grouting should be done, however, before any appreciable reservoir storage takes place to avoid grouting operations being performed against reservoir head or in an environment of high groundwater velocity.

d. Grouting and Drainage Galleries.

(1) Plans for the larger dams generally include grouting galleries from which holes for curtain grouting can be drilled and grouted. The galleries provide access to the hole locations and working space in which drilling and grouting can proceed without interference with or interruption from other construction activities. Galleries also provide access to locations for additional grouting, should any additional treatment be required after the project becomes operative. Access shafts to the gallery should be designed to accommodate the grouting equipment.

(2) A gutter located along the upstream wall of the gallery along the line of grout holes will (a) carry away drill water and cuttings from the drilling operations; (b) carry away wash water and waste grout from the grouting operations; (c) catch the discharge from drains that are usually located on monolith joints; and (d) permit a visual check to be made on the flow from each drain hole after the dam is in service. A gutter along the downstream gallery wall is also frequently provided and is advantageous in that (a) the drain is located closer to the gutter, resulting in a shorter cross drain easier to keep clean and (b) separate flow rates can be determined from the foundation drains, whereas the upstream gutter will collect flows from joint drains. Weirs can be installed to monitor foundation flows. The gutters should be sufficiently wide and shallow to accommodate the pipe on the greatest angle required. The floor of the gallery should be as near the rock surface as feasible to conserve on pipe or on drilling through concrete and to provide uplift relief at the lowest feasible elevation. However, the gallery floor should preferably not coincide with a lift joint. The gallery should be located near the upstream side of the dam to provide the maximum reduction in overall uplift.

(3) Galleries similar to those shown in figure 7-1 are also incorporated in many lock structures to aid grouting operations. The lock filling and emptying conduit may be used in lieu of a gallery when the lock dimensions do not allow room for a grouting gallery. In any case, a delay in grouting operations until some concrete has been placed is desirable.

(4) Failure to provide ready access for drilling of the grout holes can seriously affect the quality of the constructed grout curtain. Attempts have been made to provide access to grout holes without going to the expense of including galleries. However, the most effective means, which is always

accessible, has been to provide a gallery fairly close to the foundation elevation from which the main curtain grouting and drainage operations can be performed. The need for possible split spacing should be considered in the design of the concrete structure beneath the gallery.

e. Piping.

(1) Grouting from galleries or from intermediate concrete lift surfaces requires the drilling of holes either through embedded pipe or through the concrete with the hazard of encountering reinforcing steel in the drilling. The former procedure is preferable in that it allows the bottom of the pipe to be set so as to intersect observed fractures or other features to be grouted prior to concrete placement. Sections A-A in figure 7-1 show a satisfactory arrangement and size of piping where drilling and grouting are to be done from a gallery.

(2) Although a clearance of 1/4 inch is considered ample for diamond drilling, the use of pipe smaller than 2-1/2 inches in diameter for grout holes is inadvisable for embedment in concrete because of the possibility of bending or other damage to the pipe during the concrete placement operations. Larger diameter pipe may cause the drill rods to "whip" because of the unsupported length, which causes the bit to chatter. The decrease in velocity of the drill water during drilling operations as the water flows upward from the grout hole into the larger diameter pipe allows cuttings to accumulate at the bottom of the pipe. The cuttings may fall back into the hole when drilling is stopped and the drill water is shut off, and the cuttings have been known to bind the drill rods in the hole to the extent that rod removal is difficult. In stage grouting operations, the larger the diameter of the embedded pipe the less the chance of being able to recenter the drill bit in the hole, where a previously grouted stage must be redrilled, and, thus, the greater the likelihood that redrilling will be in rock instead of in grout. Smaller diameter pipe can be set inside previously installed larger pipe as a guide for the drilling. The larger diameter pipe also has the disadvantage of being more costly.

(3) Care should be used in positioning the guide pipes to be embedded in the concrete, because the angle or alignment of each pipe fixes the direction of the hole that will be drilled through the pipe. Small deviations in alignment will be greatly magnified in the lower reaches of the holes, especially where deep holes are to be drilled, and wide gaps will be left in the lower part of the grout curtain. The lower ends of the pipes will need to be anchored firmly in place to maintain the alignment of the pipes during concrete placement operations. Alignment may be maintained by grouting the pipe ends into the foundation rock to a depth of about 6 inches, or by anchoring the ends to rebars grouted into the foundation. The bottom of the pipe in the latter instance is not embedded in the foundation, which allows the contact to be grouted. Pipe ends are wrapped with burlap to prevent grout or concrete from entering the pipe. The top of each pipe should also be secured during concrete placement to maintain alignment.

(4) The 12-inch nipples shown in figure 7-1 and 7-2 at the tops of the grout pipes should be wrapped with building paper or other material to prevent bonding. The nipples can then be removed and the holes can be plugged after grouting has been completed if that is considered desirable.

(5) Factors involved in setting the pipe include direction, angle, and spacing of the proposed holes. Where necessary, additional split spaced holes can be drilled through the concrete. Horizontal or near horizontal holes may be required in steep abutment areas to properly grout relief joints. Holes are frequently fanned out in the abutment areas to provide complete coverage and overlap with grout holes outside the concrete structure, as shown in figure 7-1.

7-2. Earth and Rockfill Dams.

a. Grouting Patterns.

An embankment profile and sections illustrating typical grouting patterns are shown in figure 7-2. Additional guidance is given in EM 1110-2-2300.

b. Foundation Preparation for Grouting.

(1) Provisions should be made for a thorough cleanup of the rock surface to be grouted and adjacent areas on either side of the grouting operation. This cleanup allows mapping of the foundation and an evaluation of the grouting program as it progresses and facilitates observation of any surface leaks that may occur. The cleaned area also aids in ascertaining the need for special grout holes to intersect and treat prominent or unique discontinuities. It should be noted that weathered, broken, highly jointed and fractured, or horizontally bedded rock with soft seams may not be effectively treated by grouting. Wherever possible this type of material should be removed.

(2) Although surface breakouts or leaks will indicate the distribution pattern of the grout at the foundation surface, such leaks are wasteful and may not permit the development of the desired injection pressure buildup. In the interest of completely treating the critical upper surface, the following methods may be used to control surface leakage.

(a) Use of the accepted methods of rock foundation treatment discussed in paragraph 4-2b of EM 1110-2-2300 should be considered prior to grouting.

(b) Leave the foundation excavation several feet high and set the bottom of the nipples or packers at final grade. After grouting is complete, remove material to final grade, taking care not to disturb the grouted rock. This facilitates treatment of the final upper surface of the foundation and protects it from damage by grouting equipment. Construction of a temporary earth embankment along the grout curtain serves the same purpose, but may hinder washing operations and will mask the leakage patterns.

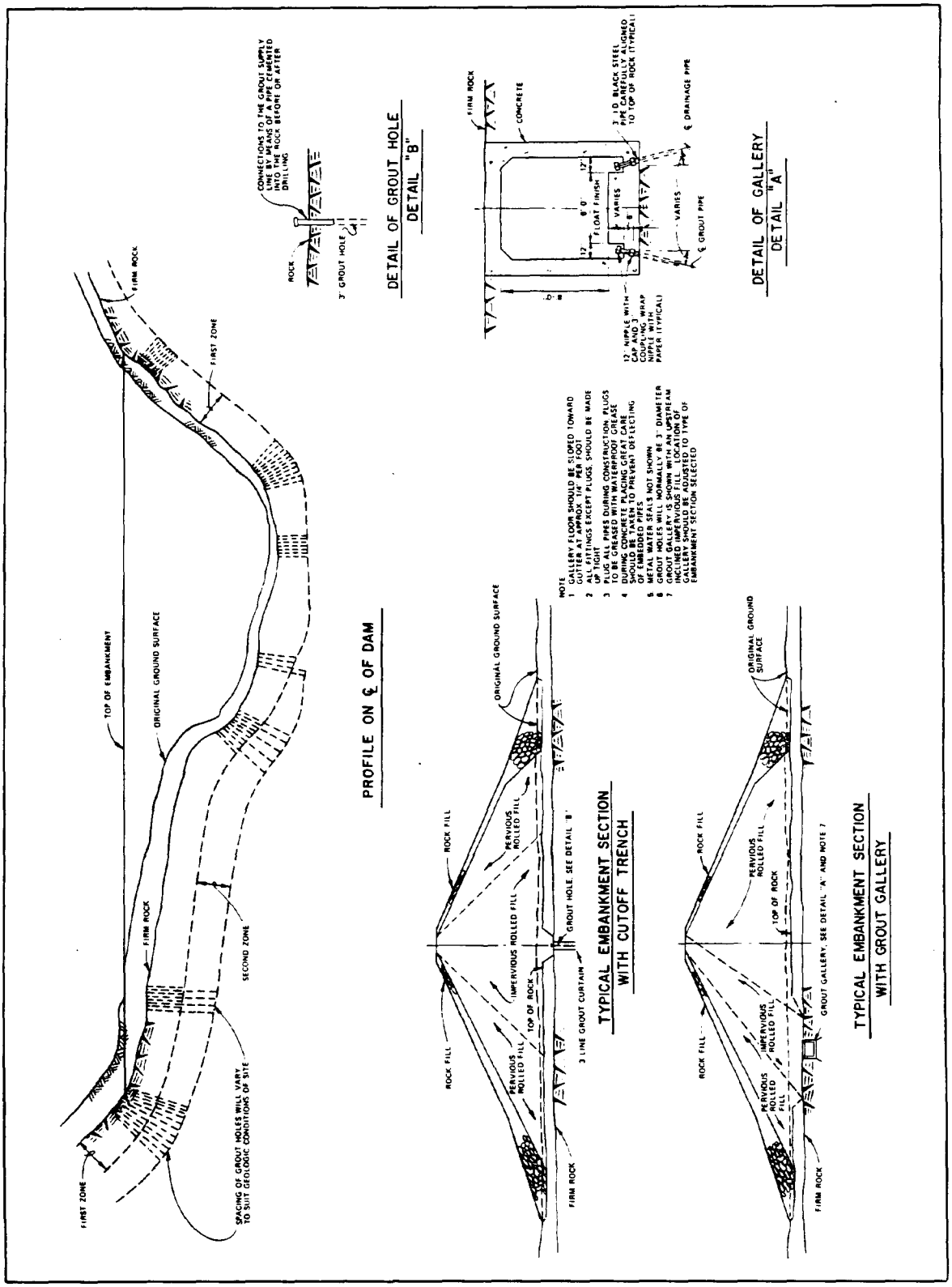

Figure 7-2. Grouting patterns

(c) Caulk the leaks in the surface of the bedrock with wooden wedges, dry pack cement grout, oakum, burlap, or other materials.

(d) Pump a thick grout into the hole until it surfaces and fills the fissure, then discontinue the pumping until the grout is set up sufficiently to plug the leak. If the effectiveness of subsequent grouting in lower zones may be questioned because of the tendency of the previous leaks to reopen and relieve grouting pressure, set a packer near the bottom of the previously grouted zone. After the final depth is grouted, grout at full pressure from the pipe connection at the collar of the hole.

(e) Dike the leak and allow the grout with added accelerator to set up.

(f) Add additional shallow surface holes to distribute grout at shallow depths.

c. Grout Hole Connectors. Grouting is usually done through pipe nipples grouted in the tops of the holes or through packers. Where rock is too soft or friable to hold them, the nipples may be embedded in concrete. If problems with nipples breaking loose are anticipated, the specifications should contain provisions for using a packer.

d. Area/Blanket/Consolidation Grouting. Grout holes usually less than 30 feet deep on a closely spaced grid pattern are often used in the upstream portion of the foundation or under the entire impervious core contact area. This pattern consolidates the critical upper surface and treats any unseen weak zones, and affords better protection of the core from piping. The operation should be accomplished prior to curtain grouting to take advantage of pretreatment of the upper zone.

e. Grouting Through Embankments. In new dam construction the grout curtain should be completed prior to construction of the embankment for the following reasons:

(1) Hydraulic fracturing or washing of the embankment may occur if fluid is used in drilling.

(2) Drilling with air below the piezometric surface creates high differential pressures in the hole, which may result in collapse of the hole or fracturing of the embankment.

(3) Washing and pressure testing are critical because of the danger of erosion at the embankment-foundation contact.

(4) No observations can be made as to grout travel or treatment of specific critical areas.

(5) The tight pattern of holes will probably not be constructed as designed because of deviations during drilling.

(6) Use of high grout pressure may heave and crack the embankment.

(7) Grout travelling downstream through the foundation may affect drainage.

(8) Grouting through an embankment invariably involves higher costs. Grouting has been done through completed dams as a remedial measure. Casing should always be used through the embankment and grouting should only be done through packers.

f. Grouting Galleries and Adits. Grouting and drainage galleries are common in concrete dams and have been used in earth- and rock-fill dams. Adits in abutments have been used for grouting and drainage on Corps dams. Adits and galleries are constructed prior to placement of the embankment as reinforced concrete structures in bedrock or as tunnels excavated in the foundation or the abutments. Grouting galleries have been used as an expedient to allow the embankment to be constructed and grouting to be done during, or following, completion of earthwork. See figure 7-2. Some possible benefits from using adits and galleries in earth- and rock-fill dams are:

(1) Construction of the embankment can be carried out independently of the grouting schedule.

(2) The advantages of grouting with the additional weight imposed on the foundation (higher grout pressures) can be realized, while most of the objection to grouting through the embankment can be eliminated.

(3) Adits are also excellent exploratory tools that give detailed data on the nature of the rock discontinuities to be treated.

(4) Galleries and adits allow access to the foundation during and after reservoir filling so that additional grouting can be planned and results evaluated from direct observations.

(5) If galleries and adits are used for drainage holes, pressure can be partially relieved immediately downstream of the grout curtain.

(6) Galleries and adits can be used to house foundation instrumentation outlets. Design of the gallery and impervious section of the dam must consider that the full reservoir head will be dissipated through the core immediately above the gallery.

g. Grout Caps. Concrete grout caps have been used for earth dams, particularly in areas of weak or highly fractured rock, to impede surface leakage and to provide anchorage for grout connections. Grout caps are constructed as

concrete trenches encompassing all grout lines, and are usually 3 to 6 feet deep, but may be large and deep enough to contain a grouting gallery for future inspection and remedial grouting. Use of a grout cap has the following advantages: (1) minimizes development of surface leaks, (2) provides a leveling course for operations, (3) trench construction ensures treatment of the upper foundation by providing a positive cutoff and added protection for the embankment, (4) creates a wider grouted area by forcing grout to travel longer horizontal distances, (5) tends to eliminate the ungrouted upper few feet, which may be experienced with nipples, and (6) eliminates problems with setting nipples (if nipples are set in concrete or drilled after completion). Disadvantages include (1) masking of breakouts, (2) rock damage during excavation for the cap, and (3) possible uplift or cracking creating seepage paths through the concrete. Caution. A grout cap will not permit a significant grout pressure increase in the upper zone of the grout curtain, and must be strong enough to handle loads from the placing and compacting of overlying fill.

h. Abutment Grouting. The same applications for general grouting apply to abutment grouting. When there is a change in orientation of holes from those of the adjacent foundation, additional grout holes should be fanned at the change in attitude or the segments of the curtain overlapped to ensure the continuity of the grout curtain. All or part of the grout curtain can be constructed from adits, usually at a higher cost but with the same potential benefits as described in e above. The surface from which grouting operations are performed can be greatly improved through use of the treatments outlined in paragraph 4-2c, of EM 1110-2-2300, before grouting.

i. Reservoir Rim Grouting. Under certain geological and project operation conditions, leakage from the reservoir may be a problem and require treatment. Loss of water through narrow ridges or through karst topography could affect the economics and safety of the project, and the regional groundwater conditions. The potential for these conditions should be identified during the exploration and design stages. Methods include mapping the reservoir, exploratory holes, a detailed groundwater survey, and pump tests to determine potential leakage. If considered necessary, rim grouting should be included as a part of the dam contract and should be designed to reduce leakage to an acceptable level. A decision to defer rim grouting until later might be made in some instances, and would be an acceptable alternative if access is assured. Monitoring in this case should be accomplished through the use of observation wells placed strategically around the rim.

j. Blasting. Special attention should be directed to limitations on blasting after grouting. It may be necessary to monitor the blasting and establish limits for each project. As a rule, grouting should be accomplished after all blasting in the area has been completed.