Chapter 7
Seepage Control Measures and Features

7-1. General

Unless properly treated, seepage of reservoir water through a dam foundation and abutments can present serious problems regardless of the type of foundation--rock, soil, or piling. The primary purpose of controlling the seepage of water through a dam foundation is to prevent the foundation material from piping and washing away, which could result in structural failure due to loss of support. A secondary purpose of controlling seepage is to reduce foundation uplift pressures. Impervious (clay) blankets and cutoff walls, in particular, lengthen the seepage path and thereby reduce uplift pressures. However, where foundation drains are provided, it has been Corps practice in the design for sliding and overturning stability to either disregard the benefit of the drains or consider the drains only partially effective in limiting uplift pressures. However, maximum possible uplift values should be used for checking foundation pressures and relief of pile loadings. Piezometers have been used very effectively in some cases to identify problems with existing seepage control systems. When filters are placed under a dam to relieve excess uplift pressures, they are of particular benefit to the stilling basin slab design because the slab without the filter would need to be anchored or of massive thickness. To attenuate, control, collect, and/or direct the seepage discharge, careful and thorough geotechnical and hydraulic studies and evaluations must be made, and proper cutoff (control) features must be designed.

a. Foundation seepage. The particular seepage problem for soil foundations and pile foundations--as well as some rock foundations which have solution channels, rock jointing, and cavities--involves piping out the foundation material. To counteract this piping, seepage control can be accomplished by a site-specific cutoff method featuring foundation grouting and drainage, steel sheet piling cutoff walls, impervious cutoff walls (trenches), concrete cutoff walls, slurry trench cutoffs, or an upstream impervious blanket.

b. Abutment seepage. To prevent the bank from failing and the stream from possibly bypassing the dam, treatment of the dam abutments should include cutoff walls, a competent bank tie-in structure, and bank slope protection.

c. Seepage analysis. Seepage analysis will generally be required. Detailed information on seepage analysis and layout details of seepage control systems are contained in EM 1110-2-1901.

d. References. Detailed information on foundation grouting, planning, and specification writing is contained in EM 1110-2-3506 and in Guide Specifications for Civil Works Construction.

7-2. Foundation Grouting and Drainage

a. Dams founded on rock.

(1) It is customary to grout and drain the foundation rock of concrete gravity dams. This practice works well for defective as well as sound formations. A well-planned, well-executed grouting program will not only reduce seepage through the rock but may also disclose the presence of unsuspected weaknesses in the foundation, thus improving any existing defects. Such a program, therefore, provides an added safety measure and ensures against future trouble.

(2) The most common design consists of a single line of grout holes located near the upstream face of the dam, drilled at five-foot centers and to a depth ranging from four-tenths to six-tenths of the maximum hydrostatic head on the base of the dam. A corresponding line of drainage holes is drilled a few feet downstream from the grout curtain and to a depth roughly two-thirds to three-quarters that of the cutoff curtain. This grout curtain may be constructed by drilling and grouting from a gallery within the dam, from the top of a specified thickness of concrete, or from the top of foundation rock. If a gallery is provided, then a series of drain holes will be drilled from the gallery and located just downstream of the grout curtain. See Figure 7-1 for layout and details of a grouting gallery with foundation grouting holes and foundation drain holes. It is essential to control the grouting pressures so that splitting and lifting of rock will not occur. Thin-bedded rocks are especially susceptible to damage by excessive grout pressures.

(3) When a stilling basin (also referred to as an “apron” or “bucket”) is founded on rock, drain holes should be provided in the rock with a collector and discharge system at the founding level for partial relief of the pressure differential. A typical stilling basin

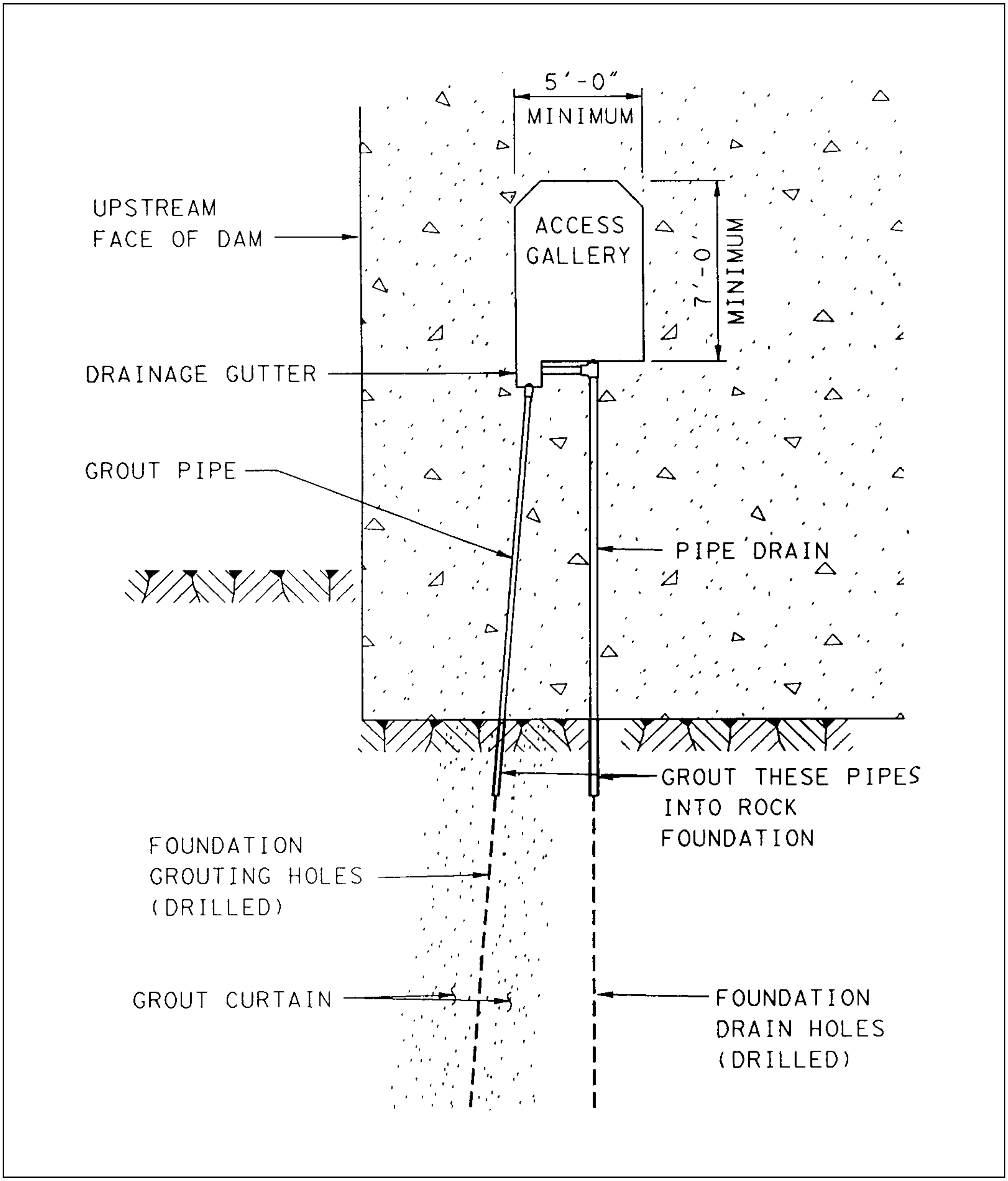

Figure 7-1. Typical grouting and drainage curtain

foundation drainage system and anchorage layout are shown in Figure 7-2.

b. Dams founded on soil or piling. Soil or pile foundations should have upstream and downstream cutoff walls (usually steel sheet piling) under the structure proper plus a cutoff wall underneath the downstream end of the stilling basin. These cutoff walls prevent piping of the foundation material due to seepage pressure. Every effort should be made to provide a reliable drainage system underneath the dam proper and the stilling basin to ensure pressure relief between the cutoffs. Plate 2 shows details of an underdrain system for soil-founded Dam No. 4 on the Red River in Louisiana (Vicksburg district). This system uses 6-in.-diam stainless steel well screen encased in a 2-ft-thick filter material, combined with access manholes, for relief of excess foundation uplift pressures which build up in the foundation. PVC (polyvinyl chloride) pipes connect the manholes to equalize the pressure in the system, and gate valves are provided so that the manholes can be unwatered to allow maintenance of the system.

7-3. Impervious Cutoff Walls (Trenches)

These compacted backfill trenches are constructed from the base of an earth dam structure through the upper pervious layers down to impervious soil layers or to bedrock. The cutoff trench is an extension of the impervious zone of the dam proper. See Plate 10 for details.

7-4. Concrete Cutoff Walls

a. Shallow cutoffs. Shallow depth cutoffs may be constructed where shallow trenches can be excavated and backfilled with concrete. This cutoff method can be applied when navigation dam piers are spaced at a clear distance between piers as wide as the navigation lock. In this case, a dam pier founded on rock may not require a transverse width (for stability) as wide as the pier spacing, and a segment of the spillway section could span between the pier bases. The spillway segment could be supported by the dam pier bases instead of being founded on rock, if overburden material exists. A concrete cutoff wall extending from the spillway segment base down to rock may be feasible. See Plate 8.

b. Intermediate depth cutoffs. An intermediate depth (up to about 80 ft) cutoff can be achieved by the slurry trench method. As the trench is excavated by conventional equipment -- backhoe, dragline, etc. -- the bentonite slurry is introduced to support the sides of the excavation. When the excavation reaches the design depth, impervious material is placed under controlled conditions to establish the cutoff. For major, permanent structures, the slurry should generally be displaced with tremie concrete.

c. Deep cutoffs. When concrete cutoffs need to extend to a great depth below either a concrete or an earth dam structure, a 2.5- to 3-ft-wide excavation is drilled by special equipment and the excavation walls supported by bentonite slurry, which is displaced when the concrete is placed by the tremie method.

7-5. Sheet Pile Cutoff Walls

Continuous steel sheet piling cutoff walls are used for soil-supported and pile-supported concrete dam structures. The piling should be used upstream and usually also downstream and should be embedded 1 to 2 ft into the base of the concrete at the top. The piling will be driven to a depth that satisfies the seepage cutoff requirements indicated by analysis. See Plate 2 for a typical steel sheet pile cutoff. The following discussion will provide guidance for the use of cold-formed, Z-type steel sheet piling as an alternative to hot-rolled, Z-type steel sheet piling. This type of piling is used for straight wall installations where beam strength (bending) is a primary design consideration. While the sheets are required to interlock, no supplier has ever warranted a specific interlock tension value. The hot-rolled piling and the cold-formed piling have markedly different interlock configurations, as depicted in Figure 7-3.

a. Section stability. While neither the hot-rolled nor the cold-formed shapes have been sized to meet any width-depth or width-thickness criteria, it appears that the configuration of the cold-formed sections results in section instability. Currently, there exist no criteria for section stability; therefore, in applications where high stresses are expected, appropriate section stability checks should be made.

b. Seepage. The loose fit of the cold-formed sheets can result in greater seepage than occurs with hot-rolled. However, with time, the interlocks may silt-in and provide adequate control of seepage. Analyses considering the magnitude of seepage and the potential for silting-in should be performed to determine if the cold-formed sheets are acceptable.

c. Installation. Problems have been reported regarding the tendency to drive the cold-formed sheets out of interlocks in areas of hard driving. Also, due to the loose fit, vertical plumb in the plane of the wall is difficult to maintain.

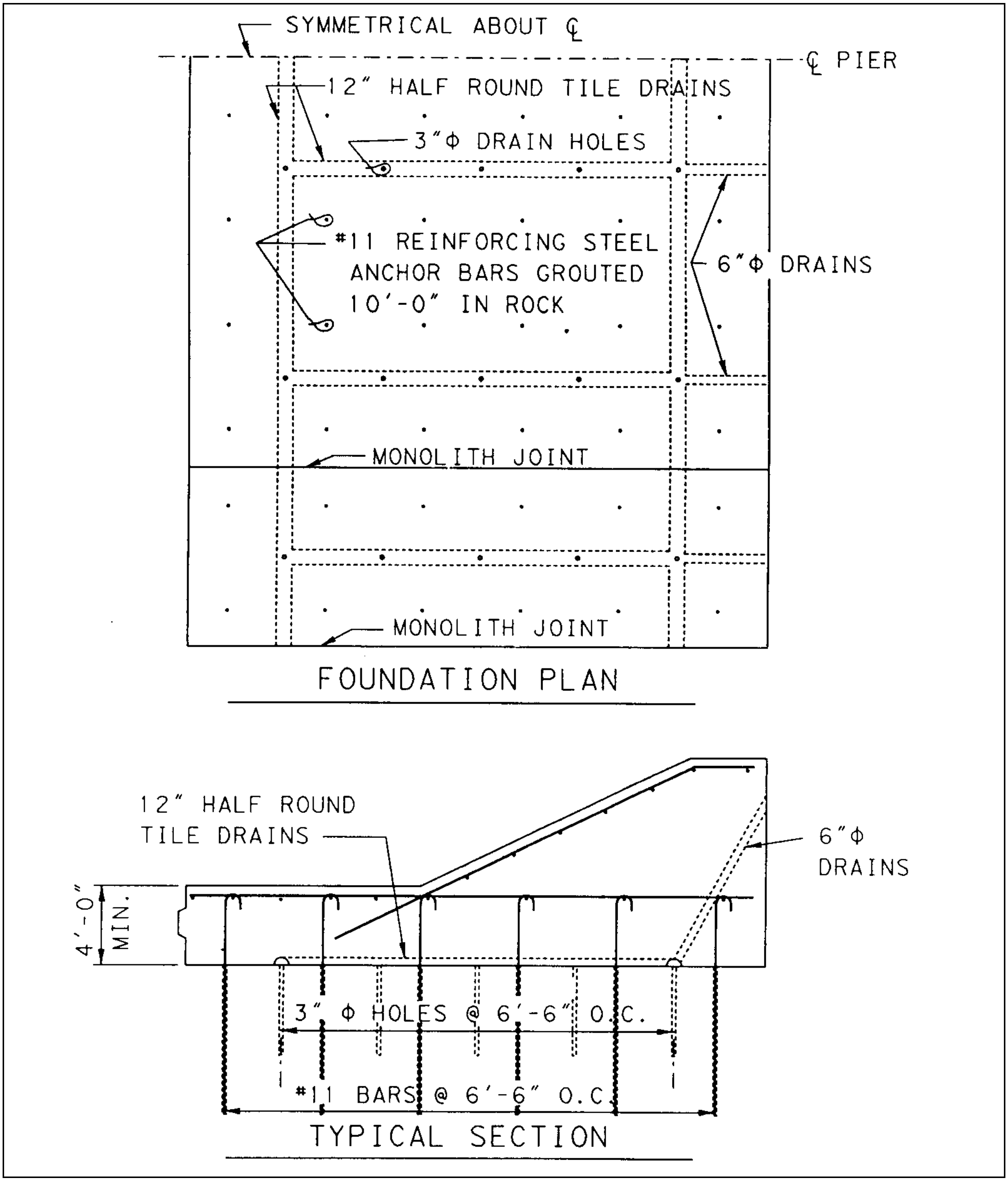

Figure 7-2. Stilling basin drainage and anchorage

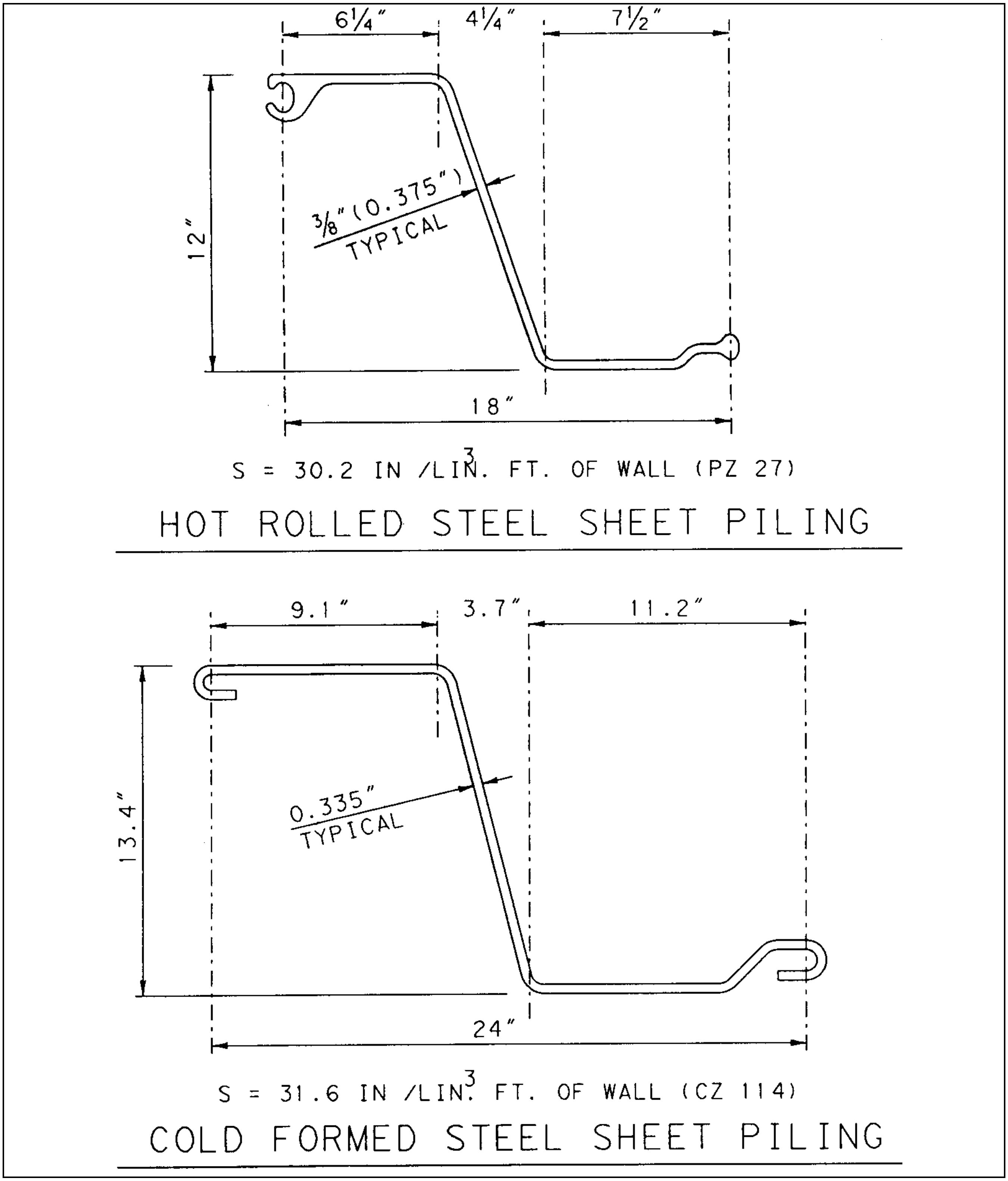

Figure 7-3. Steel sheet piling

d. Corps of Engineers specifications. Guide Specification CW-02411 allows for the use of heavy-gauge cold-formed piling as an alternative to hot-rolled steel sheet piling but gives the following recommendations:

(1) Hot-rolled steel sheet piling sections. Hot-rolled steel sheet piling sections are suitable for applications where interlocked joint strength in tension or section stability is a primary design requirement. Section stability (biaxial stress) is a consideration in highly stressed applications only.

(2) Hot-rolled, light-duty steel sheet piling sections. Hot-rolled, light-duty steel sheet piling sections and cold-formed steel sheet piling sections are suitable for average-depth applications such as trench sheeting and bulkheads in moderate water depths. They are not suitable for applications where they are subjected to high concentrated wale loads or where interlocked joint strength in tension or section stability is a primary design requirement.

(3) Cold-formed, light gauge steel sheet piling sections. Cold-formed, light gauge steel sheet piling sections are suitable for applications with a required minimum sheeting thickness of 0.250 in. or less, low bending and corrosion resistances, and minimal required interlocked joint strength in tension. The corrosion resistance of light gauge sheet piling can be increased by applying a protective coating.

e. Conclusions. Since the use of a different type of piling will depend on site-specific conditions, each Corps office needs to make its own decision on whether or not to use the cold-formed steel sheet piling. The decision should be based on site-specific foundation data, design requirements, and the importance of obtaining the best possible "in-place" assembly to prevent excessive amounts of water from passing through the interlocks. In locations where the piling is installed in a pure bending design requirement and where excessive flow of water through the interlocks with undesirable displacement of material is not a controlling factor, the cold-formed piling should perform equally as well as the hot-rolled piling (assuming the equivalent section properties).

7-6. Upstream Impervious Blanket

An upstream impervious blanket will frequently be advantageous for soil and pile founded dams, as it increases the length of the seepage paths and thereby reduces uplift pressures under the structures and the potential for seepage problems. The blanket will usually be of clay material (rather than concrete) for purposes of economy. An impervious membrane, in lieu of a clay blanket, is not recommended because of the high risk of punctures and tears. Typically, the blanket will be a minimum of 5 ft in thickness, and will extend upstream as necessary for seepage control and extend as necessary to the adjacent channel slopes. To account for potential separation between the blanket and structure, an impervious membrane, with laps to allow lateral movement without tearing the membrane, is attached to the face of the structure and embedded into the blanket. Refer to Plate 11 for details.