CHAPTER 6

DESIGN AND CONSTRUCTION DETAILS AND CAUSES OF UNSATISFACTORY PERFORMANCE

6-1. Foundation Preparation. Earth foundations should be properly compacted and should be clean and damp before concrete is placed. Rock foundations should be cleaned and given any other necessary treatment to ensure proper bond of concrete to rock. Some rock foundations, primarily shales, require a protective covering such as unreinforced concrete to protect them from deterioration after being exposed and before concrete placement, unless the final excavation can be performed close enough in time to the placement of the structural base slab. When a protective coating is used, it must be such as to ensure proper bond.

6-2. Concrete Materials. Consideration should be given to the materials that are economically available for a particular project. EM 1110-2-2000 describes concrete materials requirements; all options which are applicable to the work and which include available materials should be investigated. Concrete proportions should be selected to satisfy strength and durability requirements.

6-3. Constructability. The dimensions of the wall should be such that reinforcement and concrete can be properly placed. EM 1110-2-2000 provides guidance for concrete placement. Guide specifications CW 03301 and CW 03305 provide detail requirements for concrete placement. The top thickness of the stem for cantilever concrete walls over 8 feet high and for base slabs should be a minimum of 12 inches to facilitate concrete placement. Stems not over 8 feet high with one layer of vertical reinforcement may be 8 inches thick. The wall section should be designed for simplicity and maximum reuse of forms. Any construction constraints due to the location of the wall should be included in the design.

6-4. Joints. Walls are designed with joints to allow for expansion, contraction, and/or to divide the structure into convenient working units. The locations of all horizontal and vertical joints should be shown on the drawings.

a. Expansion Joints.

(1) General Needs and Uses. Expansion joints are designed to prevent the crushing and distortion (including displacement, buckling, and warping) of the abutting concrete structural units that might otherwise occur due to the transmission of compressive forces. Compressive forces may be developed by expansion, applied loads, or differential movements arising from the configuration of the structure or its settlement. In general, expansion joints are needed to prevent spalling and sometimes to break continuity. In relatively thin reinforced concrete walls such joints should be located where considerable expansion or unequal settlement is anticipated, e.g., at changes in alignment or grade, at abrupt changes in section or at intermediate points when needed. In massive reinforced concrete walls and in gravity walls on rock, expansion joints usually are not provided unless required at abrupt

changes in section or at angle monoliths to relieve thrust from expected expansion. Otherwise, adequate chamfers on each side of each contraction joint usually are sufficient to prevent spalling. Where temperature variations are extreme, modification of these criteria may be required. Reinforcing steel, corner protection angles, and other fixed metal embedded in or bonded to the surface of the concrete should not extend through an expansion joint. Where water tightness is needed, water stops are provided as outlined in paragraph 6-4e.

(2) Joint Filler. The thickness of joint filler necessary to provide stress relief at a joint should be determined from the estimated initial contraction and subsequent expansion from maximum temperature variation. Premolded expansion joint filler and adequate chamfers should be used.

b. Contraction (Monolith) Joints. These are intentional planes of weakness designed to regulate cracking that might otherwise occur due to the unavoidable, often unpredictable, contraction of concrete structural units. Contraction joints also divide the structure into convenient working units and thus also serve as construction joints. Since it is impractical and uneconomical to provide sufficient reinforcement to prevent cracks entirely, it is desirable to control their location, insofar as is practicable, by vertical contraction joints, across which reinforcement does not extend. No exact rules for the location of such joints can be made. Each job must be studied to determine where the joints should be placed, taking into account the requirements of structural design, the volume of concrete which can be placed economically in a single working unit, and the economical use of form units. Typically, contraction joints have been spaced 20 to 30 feet apart. Usually, a contraction joint has a plane surface without a key. For cantilever concrete walls, vertical contraction joints may be located only in the stem, and the footing may be a continuous placement.

c. Horizontal Construction Joints. These joints are provided to divide a wall into convenient working units, but they should be kept to a minimum. Keys are not permitted in horizontal construction joints as they interfere with good cleanup of the concrete surface and because a well-bonded flat surface is more dependable to transfer shear.

(1) Gravity Concrete Walls. For this type of wall the horizontal construction joint locations are dictated by the height of each lift of concrete placement. Concrete for gravity walls is usually placed in lifts up to 10 feet high. The top surface of each lift is cleaned and roughened by high-pressure water jets before placing the next lift.

(2) Cantilever Concrete Walls. For this type of wall a construction joint between the base and the wall stem should be provided. Additional horizontal joints in the wall stem should be provided by lifts approximately 10 feet high. The surface of each joint should be roughened to obtain as much shear strength across the joint as possible.

d. Joint Details for Flood Walls. For expansion and contraction joint details for flood walls, see paragraph 7-14.

e. Water Stops. Water stops are provided across joints where water-tightness is required. Nonmetallic water stops, such as rubber or polyvinyl chloride (PVC) water stops, should be used in accordance with EM 1110-2-2102. For special flood wall water stop details, see Chapter 7, Sections II and V. Careful inspection is required for water stop installation, especially with the type "U" water stop (Figure 7-9b), to see that special reinforcing is properly placed and that concrete is placed under the upper water stop in the base slab.

6-5. Soil Backfill.

a. Material Choice. Many types of material can be used for backfill. It is advisable to use locally available material when possible. Unusually poor foundation material or a need to control piping may require importation of select material.

b. Materials. Clean sands and gravels are the most suitable materials. They drain rapidly, are not susceptible to frost action, and remain stable. Silty sands, silts, and coarse-grained soils containing some clay are less desirable since they drain slowly, are subject to seasonal volume changes, and may lose much of their strength with time. Shrinkage cracks may develop in clay which, when filled with water, can cause full hydrostatic pressures to act on the wall. As mentioned in paragraph 6-7, clay, as backfill or foundation material, is involved in most retaining wall failures. During winter construction, frozen backfill material should not be used under any circumstances. This material may appear satisfactory when put into place, but it can be adversely affected when it thaws.

c. Placing and Compacting. (Refer to Chapter 3 and Appendix J for additional information on compaction.) The backfill material should be carefully selected. It should be compacted to prevent large settlements due to its own weight, with the amount of compaction required depending on the material used and the purpose of the structure. Very strict control of compaction is required when the fill is a cohesive soil. When granular fill is used, the material should be placed in thin lifts with each lift being compacted before the next lift is placed (see EM 1110-2-1911). However, precautions should be taken to prevent overcompaction which will cause excessive lateral forces to be applied on the structure. If heavy compaction rollers are used near the wall, their effect on lateral earth pressures on the wall should be considered in the design. Alternatively, the allowable weight of compactors may be restricted by the specifications to control wall pressures. It is good practice to place a layer of impervious soil that is a minimum of 12 inches thick in the upper lift of the backfill to reduce infiltration of rainwater. Backfill should be brought up equally on both sides until the lower side finished grade is reached.

6-6. Drainage.

a. Need for Drainage System. As mentioned in paragraph 6-7, improper drainage systems are one of the major causes of retaining wall failures. Drainage systems are necessary to eliminate excess hydrostatic pressures on the failure plane and the wall stem due to water seepage and surface infiltration of rainfall. In some cases the drainage system may be needed to prevent pressures from building up due to frost action in the backfill or to minimize pressures due to swelling of cohesive backfills. The kind of drainage system required depends upon the type of soil backfill, amount of rainfall, ground-water conditions, and potential frost action. Regardless of the drainage system used, the wall must have an adequate factor of safety assuming the drainage system is inoperative (see paragraph 3-23).

b. Drainage Control Methods. All retaining walls must have adequate surface drainage to dispose of surface water. As previously mentioned, a layer of impervious soil should be placed on top of the soil backfill to reduce surface infiltration of rainfall. The most effective way to control drainage within the soil backfill is an inclined drainage blanket with longitudinal drain as shown in Figure 6-1. The inclined drainage blanket will

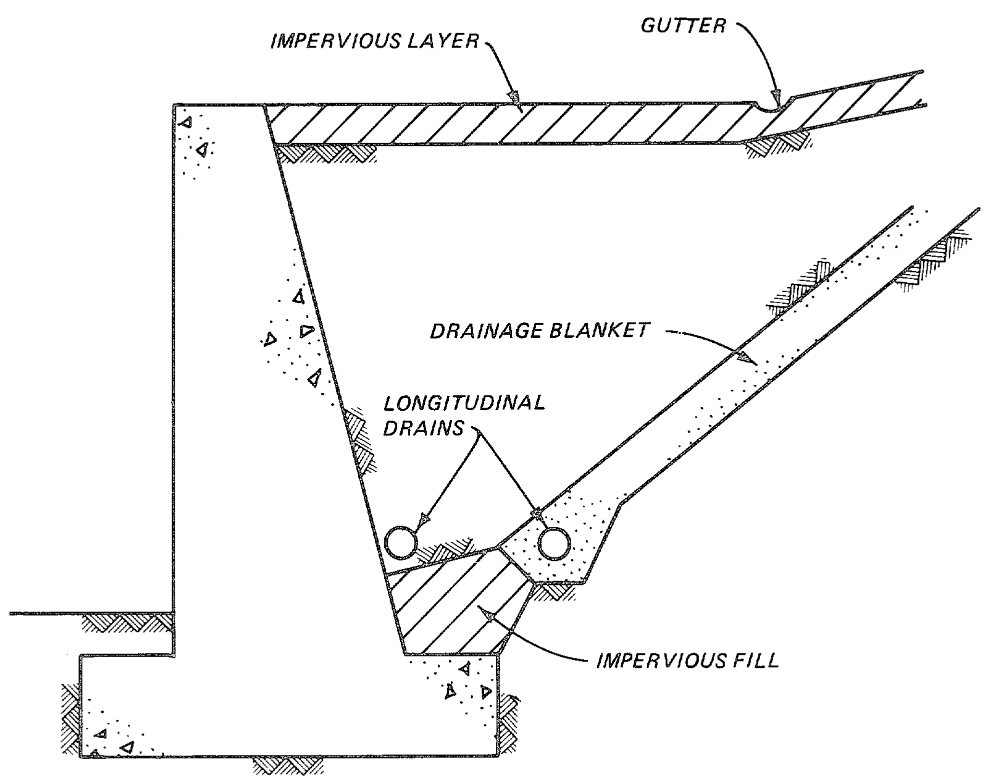

Figure 6-1. Inclined drainage blanket (after Department of the Navy 1982a)

minimize excess hydrostatic pressures on the failure plane due to groundwater seepage and surface infiltration of rainfall. A drain adjacent to the wall is less effective and will often result in higher loads against the wall (see Figure 6-2). However, for relatively low walls (typically less than 10 feet high), these higher loads may not be significant, and drains adjacent to the wall are often used. Drains adjacent to the wall may be either a drainage blanket (Figure 6-3) or a prefabricated drainage composite* (Figure 6-4). Where frost penetration is a problem, a drainage system as shown in Figure 6-5 should be used. If a cohesive soil backfill is used, a drainage system as shown in Figure 6-6 will prevent changes in moisture content of the clay and hence reduce cracking and swelling potential. Other seepage control methods are discussed in paragraph 7-4.

c. Longitudinal Drains. Longitudinal drains within drainage blankets are used for carrying the discharge from behind the retaining wall to a ditch, manhole, or other free exit. Drains should be large enough to carry the discharge and have adequate slope to provide sufficient velocity to remove sediment from the drain.** To minimize clogging, the drain should have perforations in the bottom half of the pipe at least 22.5 degrees below the horizontal axis. Where the operation of the drains is counted on to reduce the design loadings, manholes and/or inspection holes (see Figure 6-7) should be located at sufficient intervals, and at any sharp bends in the pipe, to facilitate inspection and cleanout. The terminus of the drain should have a vertical check valve (see Figure 6-8) to prevent backflooding. The end section of pipe supporting the check valve should be secured with a coupling band which can be removed for inspection and cleaning of the pipe.

d. Weepholes. Weepholes should consist of a pipe, at least 3 inches in diameter, extending through the stem of the wall. They should be protected against clogging by pockets of gravel in the soil backfill or by the use of filter fabric adjacent to the wall directly behind the weepholes. The weep-holes are commonly spaced not more than 10 feet apart vertically and horizontally.

e. Filter Requirements. Drains should be adequately protected by filter layers so that seepage water is admitted freely but movement of the soil back-fill into the drain will not occur. The piping or stability criterion is

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* Whenever a prefabricated drainage composite is used adjacent to the retaining wall, the crushing strength of the prefabricated drainage composite should be greater than three times the maximum lateral earth pressure acting on the wall. Prefabricated drainage composites are not recommended for inclined drains due to possible damage during compaction of the soil backfill and possible sliding along the plane of the drain (Smith and Kraemer 1987, Kraemer and Smith 1986).

** For a 6-inch-diameter pipe the minimum slope would be about 0.15 percent (Schwab et al. 1981).

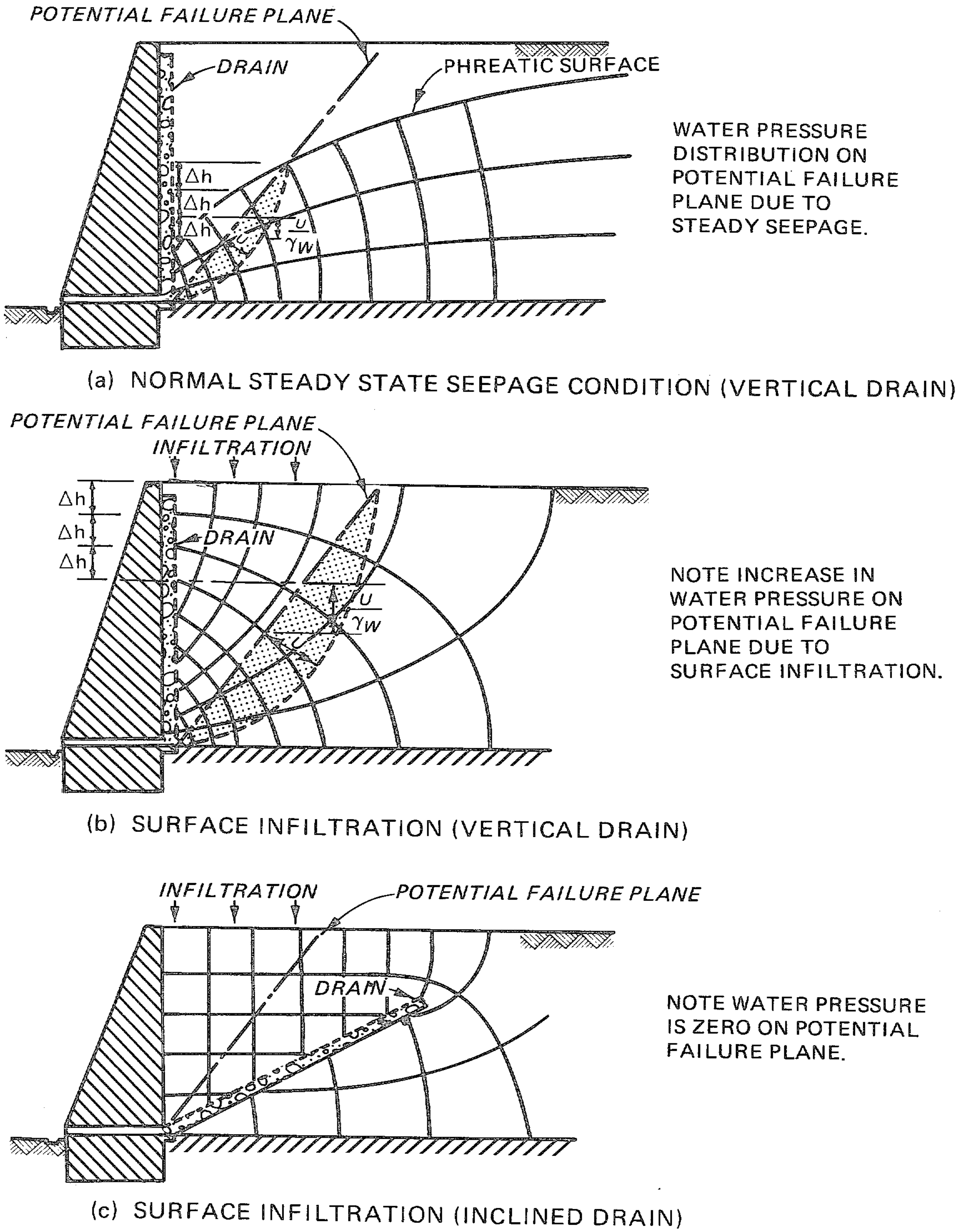


Figure 6-2. Effect of drain location on excess hydrostatic pressures on the failure plane (after Geotechnical Control Office 1982)

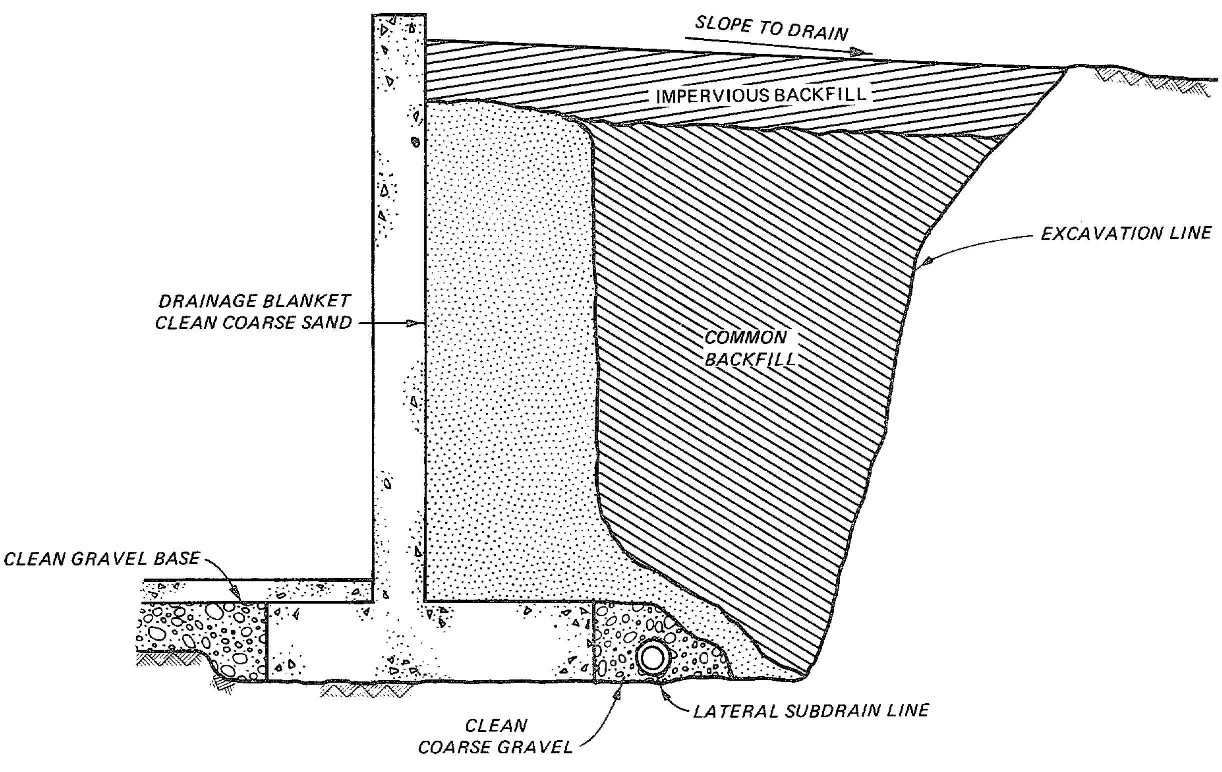


Figure 6-3. Drainage blanket located adjacent to retaining wall (after Sibley 1967)

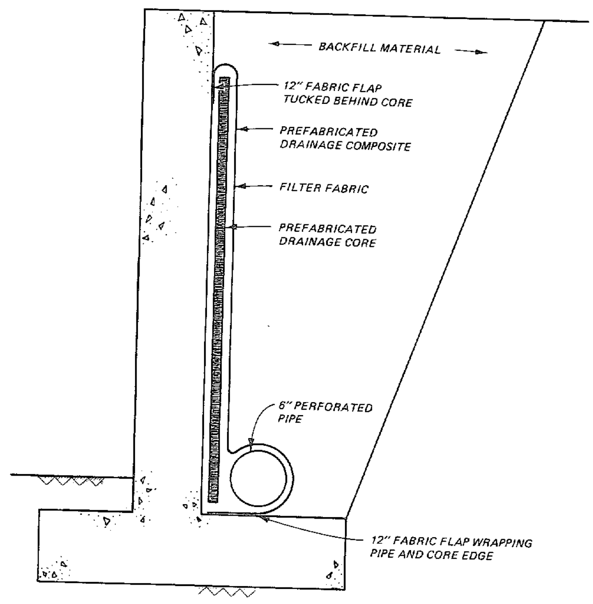


Figure 6-4. Prefabricated drainage composite used as drain adjacent to retaining wall (adapted from Carrol and Murphy 1985)

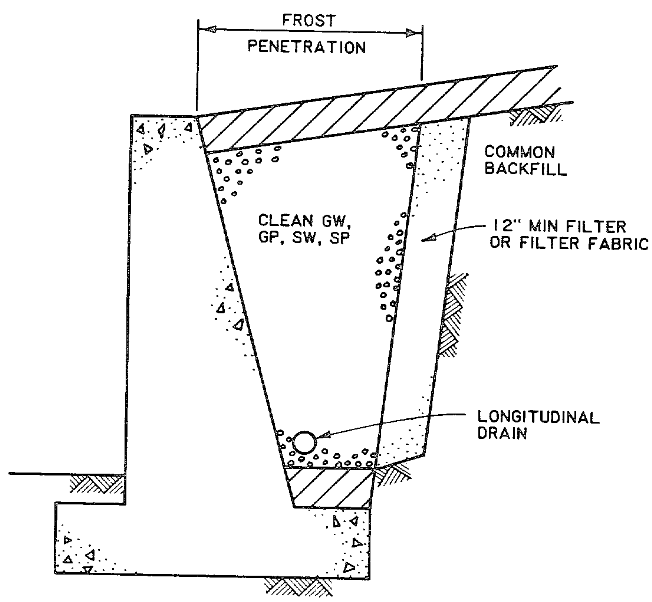
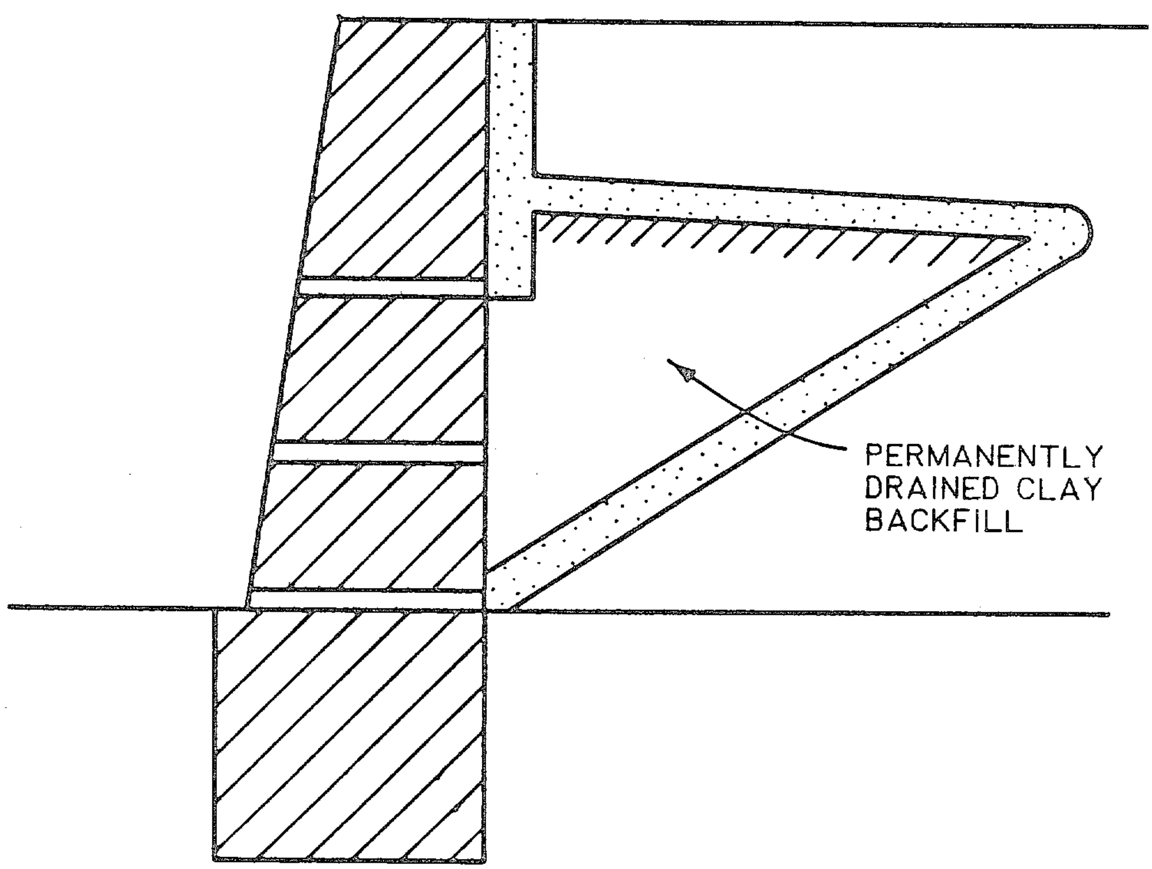


Figure 6-5. Drainage system to prevent frost penetration behind retaining wall (after Department of the Navy 1982a)



NOT TO SCALE

Figure 6-6. Drainage system to use with clay backfill (after Terzaghi and Peck 1948)

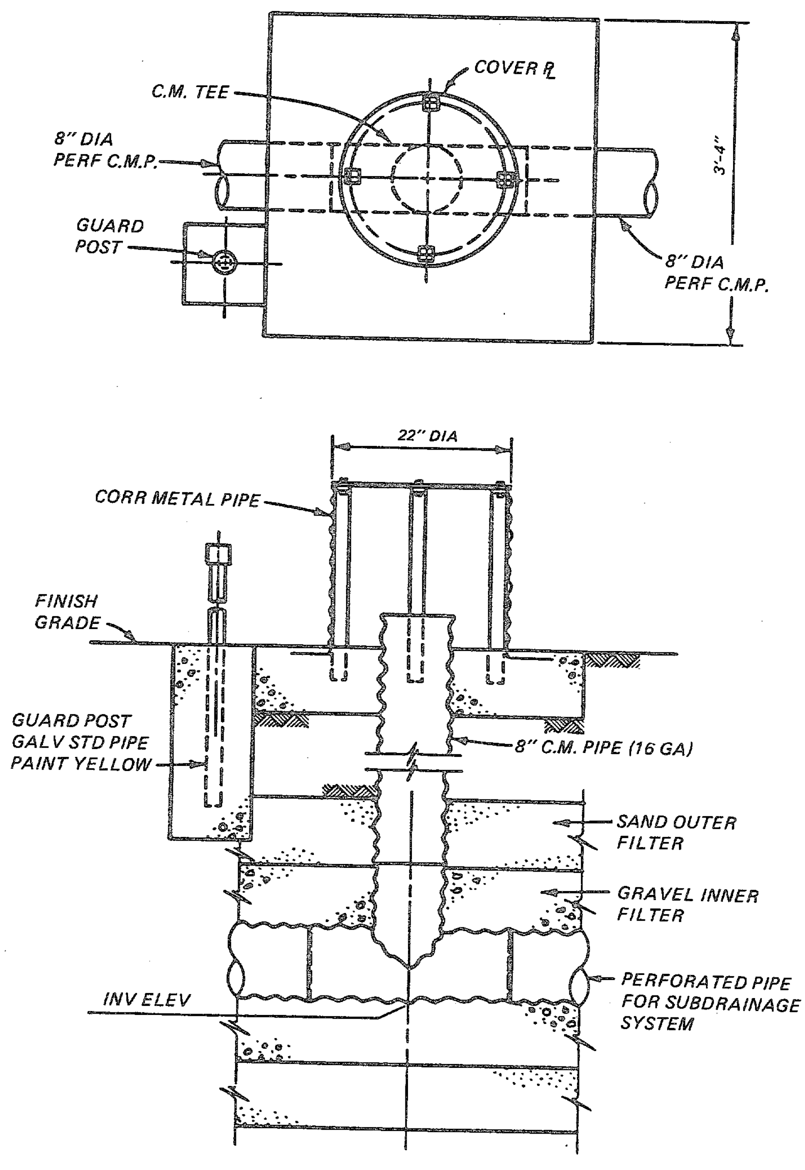
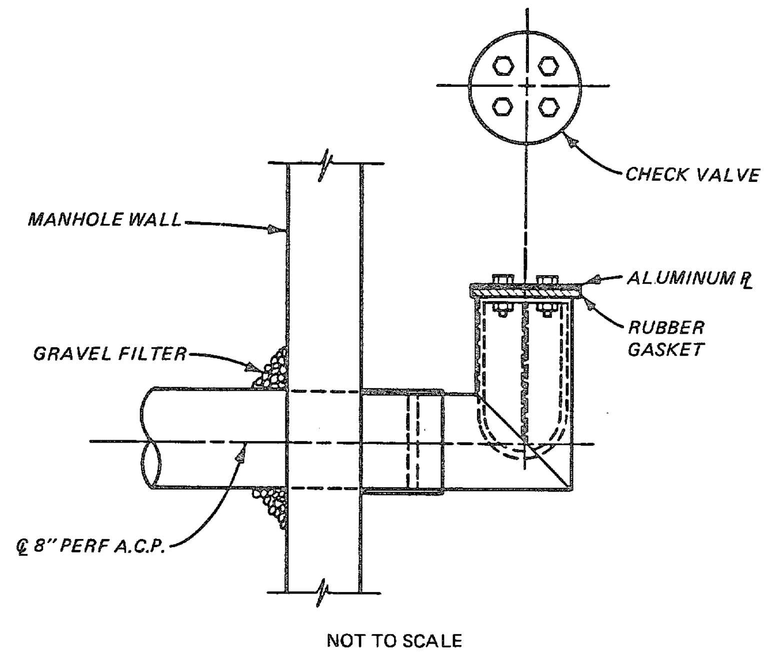


Figure 6-7. Inspection hole for longitudinal drain



TYPICAL VERTICAL CHECK VALVE SEAT

Figure 6-8. Vertical check valve at end of longitudinal drain

based on the grain size relationship between the protected soil and the filter

$$\frac{D_{15_F}}{D_{85_B}} \leq 5 \qquad [6\text{-}1]$$

where

D_{15_F} = size of filter material at 15 percent passing

D_{85_B} = size of protected soil at 85 percent passing and

$$\frac{D_{50_F}}{D_{50_B}} \leq 25 \qquad [6\text{-}2]$$

where

D_{50_F} = size of filter material at 50 percent passing

D_{50_B} = size of protected soil at 50 percent passing

To assure that the filter material is more permeable than the material being drained, the following condition must be met:

$$\frac{D_{15_F}}{D_{15_B}} \geq 5 \qquad [6\text{-}3]$$

To prevent clogging of perforated longitudinal drains, the following requirement must be satisfied:

Circular openings

$$\frac{D_{50_F}}{\text{Hole diameter}} \geq 1.0 \qquad [6\text{-}4]$$

Slotted openings

$$\frac{D_{50_F}}{\text{Slot width}} \geq 1.2 \qquad [6\text{-}5]$$

The filter material may satisfy the criteria for stability and permeability but may be too fine to meet the criteria for circular or slotted openings. Should this happen, multilayered or graded filters are required. It may be possible to substitute filter fabric for one or more of the granular filters in a multilayered filter system. Filter cloth shall conform to the requirements of guide specification CW 02215.

f. Drain Requirements. The drain must be able to carry the design flow freely without movement of soil particles. Drainage blankets may be constructed of clean sand and gravel or a prefabricated drainage composite (for certain applications). The design flow can be determined from a flow net (Cedergren 1967). For isotropic soil conditions:

$$q_b = k_b h \frac{n_f}{n_d} \qquad [6\text{-}6]$$

where

q_b = quantity of discharge through soil backfill per linear foot of retaining wall

k_b = permeability of soil backfill

h = hydrostatic head acting on retaining wall

n_f = number of flow channels in flow net

n_d = number of equipotential drops in flow net

The minimum required permeability of the drain is

$$k_d = \frac{q_d}{i_d A_d} \qquad [6\text{-}7]$$

where

k_d = minimum required permeability of the drain

q_d = quantity of discharge through drainage blanket or prefabricated drainage composite per linear foot of retaining wall

i_d = gradient of flow in the drain (1 for vertical drain, equal to slope of drain for inclined drain)

A_d = cross-sectional flow area of drain

Seepage in coarse aggregates may be turbulent and a reduction factor should be applied to the permeability as shown in Figure 6-9. The in-place permeability

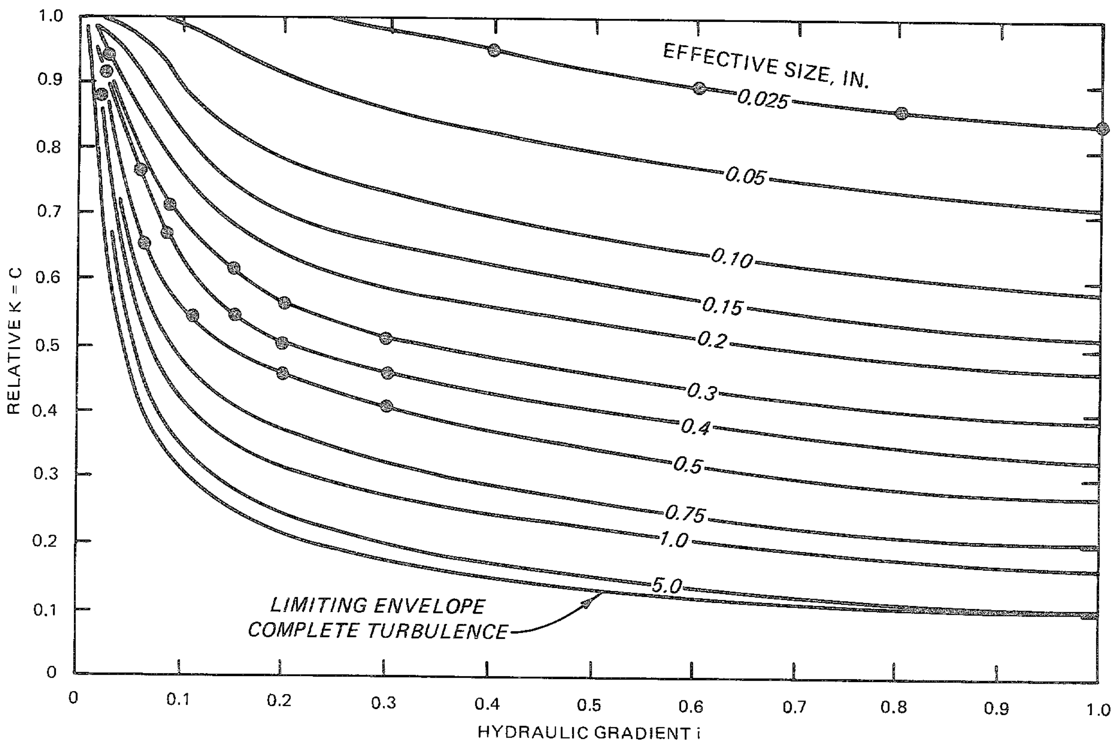


Figure 6-9. Approximation for estimating reduction in permeability of narrow size-ranged aggregate caused by turbulent flow (Cedergren 1967, courtesy of John Wiley and Sons)

should be at least 20 times that calculated theoretically. For prefabricated drainage composites the in-plane permeability will decrease with increase in lateral pressure. Therefore, the in-plane permeability must be taken at the maximum lateral earth pressure acting on the wall.

g. Construction Considerations.

(1) Sand and Gravel. Sand and gravel must not become segregated or contaminated prior to, during, or after installation. Segregation will result in zones of material too fine to meet the permeability requirements and other zones too coarse to meet the stability requirements. Contamination of the filter material from muddy water, dust, etc., during construction may clog the voids in the material and prevent proper drainage. In the event that filter or drain materials are contaminated, they should be replaced. Filter materials subject to cementation should be rejected.

(2) Prefabricated Drainage Composite. Special consideration should be given when compacting soil backfill near prefabricated drainage composites adjacent to retaining walls. Compaction adjacent to the retaining wall will induce high lateral pressures which could crush the prefabricated drainage

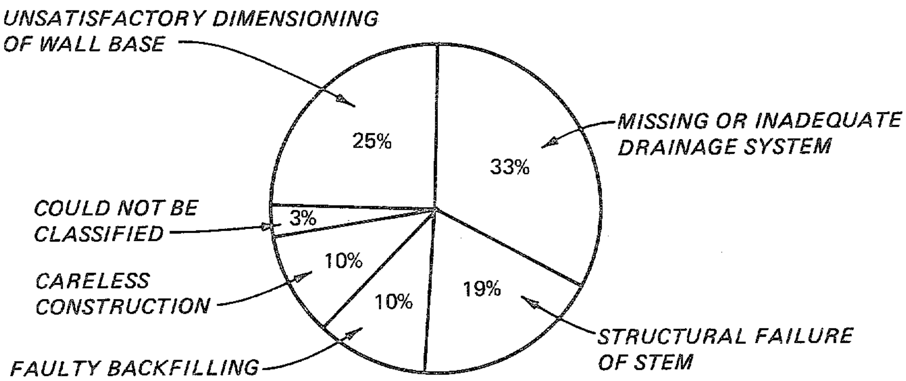
composite and/or reduce the inplane permeability. The drainage composite manufacture's recommendations for backfilling and compaction near the composite should be followed. A test section may be required to determine the acceptable operating conditions of the compaction equipment. Where crushed stone is used as the backfill material, a blanket of sand should be provided against the drainage composite to protect it against damage during compaction.

(3) Longitudinal Drains. One bad joint could render an entire drainage system inoperative. Care must be taken in compacting soil backfill over drains to prevent crushing of the pipe. Differential settlement can cause pipe joints to open up, permitting soil backfill to infiltrate. This should be minimized by attaining uniform adequate compaction of the underlying material.

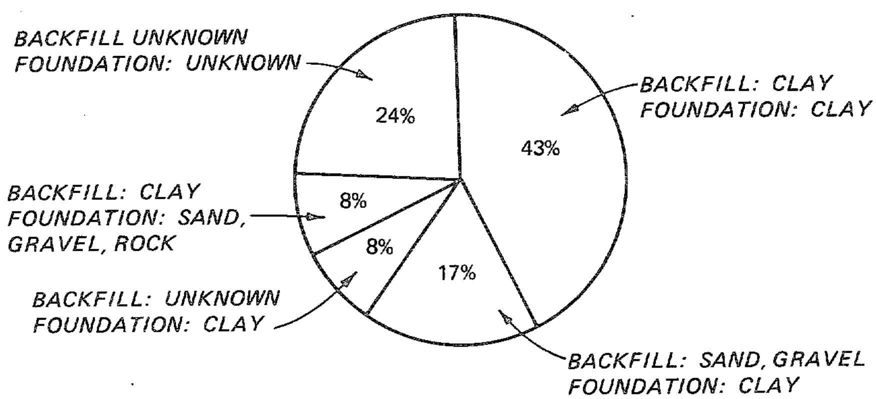
6-7. Causes of Unsatisfactory Performance. The results of two statistical studies of retaining wall failures are given in Figure 6-10 (Tcheng and Iseux 1972, Ireland 1964). It is evident that:

a. Clay, as backfill or foundation material, is involved in most retaining wall failures.

b. Improper design of the drainage system and/or the wall base is the main cause of retaining wall failure.



a. Causes of failure of rigid concrete retaining walls (Techeng and Iseux 1972)



b. Foundation and backfill material of unsatisfactory retaining walls (Ireland 1964)

Figure 6-10. Summary of experience with unsatisfactory retaining walls