CHAPTER 6

DESIGN AND CONSTRUCTION OF DIKES FOR CONTAINMENT OF DREDGED MATERIAL

6-1. Purpose. Containment dikes are retaining structures used to form confined disposal facilities. They consist primarily of earth embankments and can be constructed in upland or nearshore areas or on nearshore islands. The principal objective of a dike is to retain solid particles and pond water within the disposal area while at the same time allowing the release of clean effluent to natural waters. The location of a containment dike will usually be established by factors other than foundation conditions and available borrow material (i.e., proximity to dredge, only land available, etc.) from which there will be little deviation. The heights and geometric configurations of containment dikes are generally dictated by containment capacity requirements, availability of construction materials, and prevailing foundation conditions.

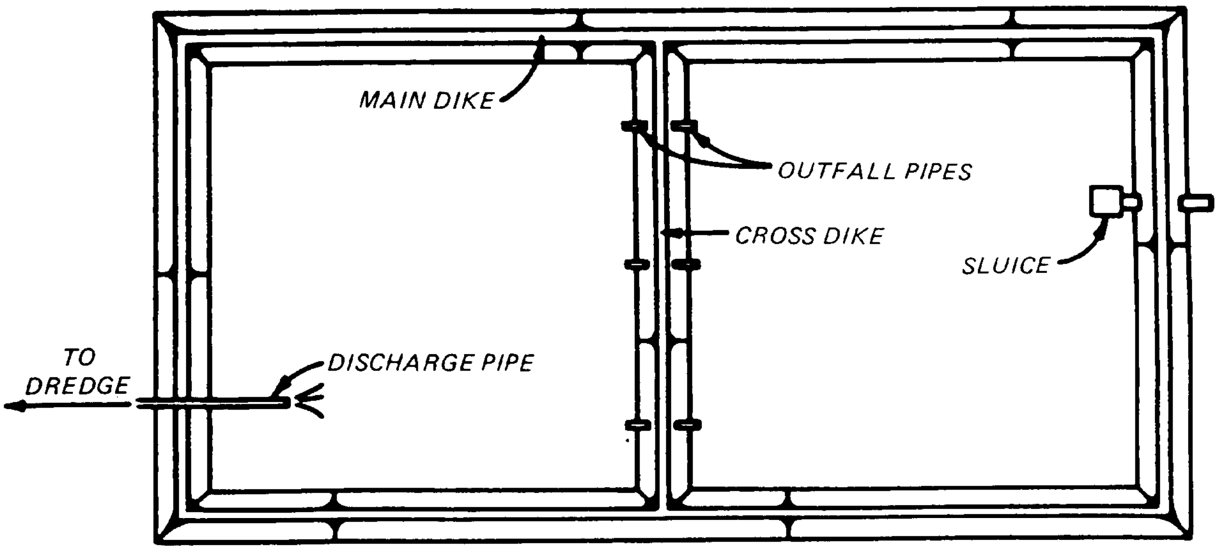
a. Types of Containment Dikes.

(1) Main dike. The predominant retaining structure in a containment facility extends around the outer perimeter of the containment area and is referred to as the main dike. Except as otherwise noted, all discussion in this chapter applies to the main dike. The main dike and two other type dikes, cross and spur dikes, which serve primarily as operational support structures for the main dike, are shown in Figure 6-1.

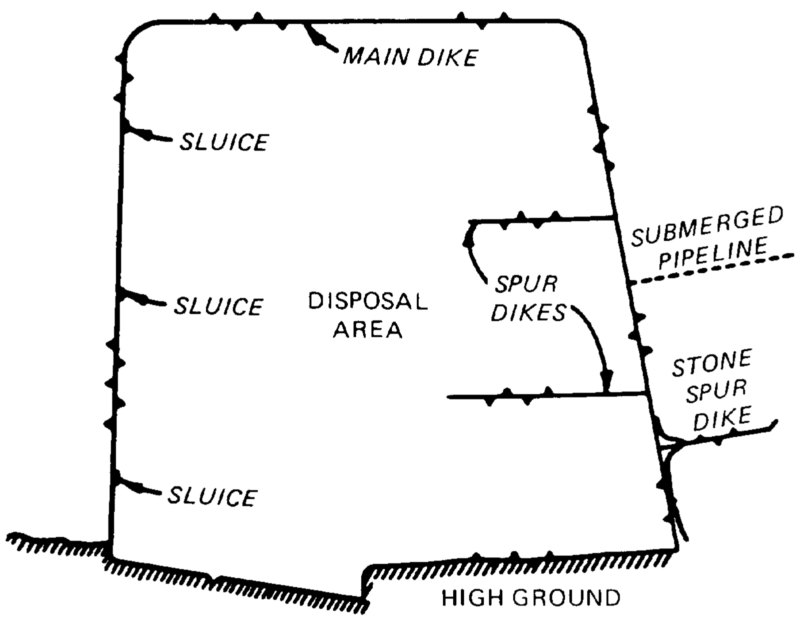
(2) Cross dike. A cross or lateral dike (Figure 6-1) is placed across the interior or the containment area connecting two sides of the main dike. This permits the use of one area as an active disposal area while another area may be used solely for dewatering. Another use of cross dikes is to separate the facility so that the slurry in one area is subjected to initial settling prior to passing over or through the cross dike to the other area. In order to accomplish this, the cross dike is placed between the dredged discharge point and the sluice discharge. A cross dike can also be used with a Y-discharge line to divide an area into two or more areas, each receiving a portion of the incoming dredged material.

(3) Spur dike. Spur or finger dikes protrude into, but not completely across, the disposal area from the main dike as shown in Figure 6-1. They are used mainly to prevent channelization by breaking up a preferred flow path and dispersing the slurry into the disposal area. Spur dikes are also used to allow simultaneous discharge from two or more dredges by preventing coalescence of the two dredged material inputs and thereby discouraging an otherwise large quantity of slurry from reaching flow velocities necessary for channelization.

b. Factors affecting design. The engineering design of a dike includes selection of location, height, cross section, material, and construction method. The selection of a design and construction method are dependent on project constraints, foundation conditions, material availability, and availability of construction equipment. The final choice will be a selection among feasible alternatives.



a. DIKED DISPOSAL AREA WITH CROSS DIKE



b. DIKED DISPOSAL AREA WITH SPUR DIKES

Figure 6-1. Examples of cross and spur dikes

(1) Project constraints. Several constraints on design are placed by the overall project needs. Available construction time and funding are always factors. The location, height, and available space for the containment dike are usually dictated by project requirements that are discussed elsewhere in this manual. The design factor of safety against structural failure is usually specified. Environmental safety and aesthetics must be considered.

(2) Foundation conditions. The lateral and vertical distribution of shear strength, compressibility, permeability, and stratification of potential foundation materials are major factors in dike design.

(3) Availability of materials. All potential sources of construction materials for the embankment should be characterized according to location, type, index properties, and ease of recovery. Available disposal sites are often composed in the near-surface of soft clays and silts of varying organic content. Since economical dike construction normally requires the use of material from inside the disposal area and/or immediately adjacent borrow areas, initial dike heights may be limited, or it may be necessary to use rather wide embankment sections, expensive foundation treatment, or expensive construction methods.

(4) Availability of equipment. Although common earthwork equipment is generally available, the specialized equipment for the soft soils desirable for use at containment sites may not be available to meet the project schedule, or the mobilization cost may be excessive. Less expensive alternatives should then be considered.

c. Construction Methods. Each type of construction method has characteristics that can strongly affect dike design. Transportation of the soil material to be placed in the dike section is either by hauling, casting, or dredging. The soil is then compacted, semicompacted, or left uncompacted. The selection of a construction method, even though based on economics, must also be compatible with available materials, available equipment, geometry of the final dike section, and environmental considerations.

6-2. Foundation Investigation. The extent to which the site investigation(s) and design studies are carried out is dependent, in part, on the desired margin of safety against failure. This decision will usually be made by the local design agency and is affected by a number of site-specific factors. Table 6-1 lists some general factors, based on engineering experience, that can be used as general guidelines in the planning stage of a project.

a. Foundation Exploration. The purpose of the foundation exploration is similar to that for the containment area as defined in Section 2-3, i.e., to define dike foundation conditions including depth, thickness, extent, composition, and engineering properties of the foundation strata. The exploration is made in stages, each assembling all available information from a given source prior to the planning and start of the next, more expensive stage. The usual sequence of the foundation exploration is shown in Table 6-2.

Table 6-1
Factors Affecting the Extent of Field Investigations and Design Studies

Factor	Field Investigations and Design Studies Should Be More Extensive Where:
Construction experience	There is little or no construction experience in the area, particularly with respect to dikes.
Consequence of failure	Consequences of failure involving life, property, or damage to the environment are great.
Dike height	Dike heights are substantial.
Foundation conditions	Foundation deposits are weak and compressible. Foundation deposits are highly variable along the alignment. Underseepage and/or settlement problems are severe.
Borrow materials	Available borrow is of poor quality, water contents are high, or borrow materials are variable along the alignment.
Structures in dikes	Sluices or other structures are incorporated into the dike embankment and/or foundation.
Utility crossings	Diked area is traversed by utility lines.

Additional guidance on the number, depth, and spacing of exploratory and/or final phase borings is given in WES TR D-77-9 (item 16), EM 1110-2-2300, ASCE Manual No. 56 (item 3), and various geotechnical engineering textbooks. Geophysical exploration methods are described in EM 1110-1-1802.

b. Field and Laboratory Tests. Field soils tests are often made during exploratory boring operations. Commonly used field tests are given in Table 6-3. Disturbed samples from exploratory and final phase borings are used for index properties tests. Samples from undisturbed sample borings are used in laboratory tests for engineering properties. Commonly used laboratory tests are given for fine-grained soils in Table 6-4 and for coarse-grained soils in Table 6-5. Additional guidance on field soil sampling methods is given in EM 1110-2-1907 and on laboratory soils testing in EM 1110-2-1906.

6-3. Construction Materials.

a. Acceptable Materials.

(1) Almost any type of soil material is acceptable (even though not the most desirable) for construction of a retaining dike, with the exception of very wet fine-grained soils and those containing a high percentage of organic

Table 6-2
Stages of Field Investigation

Stage	Features
Preliminary geological investigation	Office study Collection and study of: Topographic, soil, and geological maps Aerial photographs Boring logs and well data Information on existing engineering projects Field survey Observations and geology of area, documented by written notes and photographs, including such features as: Riverbank and coastal slopes, rock outcrops, earth and rock cuts or fills Surface materials Poorly drained areas Evidences of instability of foundations and slopes Emerging seepage and/or soft spots Natural and man-made physiographic features
Subsurface exploration and field testing and more detailed geologic study	Exploratory phase Widely but not uniformly spaced disturbed sample borings (may include split-spoon penetration tests) Test pits excavated by backhoes, farm tractors, or dozers Geophysical surveys to interpolate between widely spaced borings Borehole geophysical tests Water table observations Final phase Additional disturbed sample borings including split-spoon penetration tests Undisturbed sample borings Field vane shear tests for soft materials

Table 6-3
Preliminary Appraisal of Foundation Strengths

Method	Remarks
Penetration resistance from standard penetration test	In clays, provides data helpful in a relative sense, i.e., in comparing different deposits. Generally not helpful where number of blows per foot N* is low In sand, N-values less than about 15 indicate low relative densities
Natural water content of disturbed or general type samples	Useful when considered with soil classification and previous experience is available
Hand examination of disturbed samples	Useful where experienced personnel are available who are skilled in estimating soil shear strengths
Position of natural water contents relative to LL and PL	If natural water content is close to PL, foundation shear strength should be high
Field pumping tests used to determine field permeability	Natural water contents near LL indicate sensitive soils with low shear strengths
Torvane or pocket penetrometer tests on intact portions of general samples	Easily performed and inexpensive, but results may be excessively low; useful for preliminary strength estimates
Vane shear tests	Useful where previous experience is available Used to estimate shear strengths

Table 6-4

Laboratory Testing of Fine-Grained Cohesive Soils

Type Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the USCS	All samples
Water content	To determine the water content of the soil in order to better define soil profiles, variation with depth, and behavioral characteristics	All samples
Atterberg limits	Foundation soils: for classification, comparison with natural water contents, or correlation with shear or consolidation parameters Borrow soils: for classification, comparison with natural water contents, or correlations with optimum water content and maximum dry densities	Representative samples of foundation and borrow soils. Sufficient samples should be tested to develop a good profile with depth
Compaction	To establish maximum dry density and optimum water content	Representative samples of all borrow soils for compacted or semicompacted dikes: Compacted - perform standard 25-blow test Semicompacted - perform 15-blow test
Consolidation	To determine parameters necessary to estimate settlement of dike and/or foundation and time-rate of settlement. Also, to determine whether soils are normally consolidated or overconsolidated and to aid in estimating strength gain with time	Representative samples of compacted borrow where consolidation of dike embankment itself is expected to be significant. Representative samples of foundation soils where such soils are anticipated to be compressible On samples of fine-grained adjacent and/or underlying materials at structure locations
Permeability	To estimate the perviousness of borrow and/or foundation soils in order to calculate seepage losses and time-rate of settlement	Generally not required for fine-grained cohesive soils as such soils can be assumed to be essentially impervious in seepage analyses. Can be computed from consolidation tests
Shear strength	To provide parameters necessary for input into stability analysis Pocket penetrometer. miniature vane, unconfined compression, and Q-tests to determine unconsolidated-undrained strengths R-tests to determine consolidated-undrained strengths S-teats to determine consolidated-undrained strengths	Pocket penetrometer and miniature vane (Torvane) for rough estimates Unconfined compression tests on saturated foundation clays without joints, fissures, or slickensides Appropriate Q- and R-trisxial and S-direct shear tests on representative samples of both foundation and compacted borrow soils

Table 6-5

Laboratory Testing of Coarse-Grained Noncohesive Soils

Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the USCS	All samples
Gradation	To determine grain-size distribution for classification and correlation with permeability and/or shear strength parameters	Representative samples of foundation and borrow materials
Relative density or compaction	To determine minimum-maximum density values or maximum density and optimum water content values; should use the test which gives greatest values of maximum density	Representative samples of all borrow materials
Consolidation	To provide parameters necessary for settlement analysis	Not generally required as pervious soils consolidate rapidly under load and post-construction magnitude is usually insignificant
Permeability	To provide parameters necessary for seepage analysis	Not usually performed as correlations with grain size are normally of sufficient accuracy. Where underseepage problems are very serious, best to use results from field pumping test
Shear strength	To provide parameters necessary for stability analysis	Representative samples of compacted borrow and foundation soils. Consolidated-drained strengths from S-direct shear or triaxial tests are appropriate for free-draining pervious soils

matter. High plasticity clays may present a problem because of detrimental swell-shrink behavior when subjected to cycles of wetting and drying.

(2) Either fine-grained soil materials of high water content must be dried to a water content suitable for the desired type of construction, or the embankment design must take into account the fact that the soil has a high water content and is, therefore, soft and compressible. Because the drying of soils is very expensive, time consuming, and highly weather dependent, the design should incorporate the properties of the soil at its natural water content or should require only a minimum of drying. When the dike fill is to be compacted, the borrow material must have a sufficiently low water content so that placement and machine compaction can be done effectively. Semicompacted fill can tolerate fine-grained soils with higher water contents, while uncompacted (cast) fine-grained fill can be placed at even higher water contents. Since dike construction is normally done in low, wet areas, problems with materials being too dry are rarely encountered.

b. Material Sources. A careful analysis of all available material sources, including location, material type, and available volume should be made. Possible sources include any required excavation area, the material adjacent to the dike toe, a central borrow area, and material from maintenance dredging operations.

(1) Required excavation. Soil material from required excavations should be given first consideration since it must be excavated and disposed of anyway. Included in this category is material from adjacent ditches, canals, and appurtenant structures, as well as material from inside the containment area. This usage also eliminates the problem of dealing with borrow areas left exposed permanently after project completion.

(2) Material adjacent to dike toe. This is the most common source of dike material because it involves a short-haul distance. Hauling can be eliminated by the use of a dragline-equipped crane. Dike stability can be seriously affected if the excavation is made too close to the toe. A berm is usually left in place between the toe of the dike and the excavation to ensure dike stability and to facilitate construction. The required width of the berm should be based on a stability analysis.

(3) Central borrow area. When sufficient material cannot be economically obtained from required excavations or the dike toe, a central borrow area is often used. This may be within the containment area or may be off-site. A central borrow pit within the containment area serves to increase available containment volume. Central borrow areas can be used for either hauled or hydraulic fill dikes. Dredging from a water-based central borrow pit is usually economical for hydraulic fill dikes. Usually a deeper pit with smaller surface area is preferred since this requires less movement of the dredge.

(4) Maintenance dredging. Maintenance dredging can be a very economical source of borrow material. The coarse-grained materials from maintenance dredging are desirable for dike construction. Zones around the dredge discharge usually will provide the highest quality of material. However, fine-grained soils may not be suitable because of their very high water content and

may require considerable drying. The use of previously placed dredged material from maintenance operations has been commonly used to raise existing dikes. It is readily available and serves to increase the capacity of the containment area.

c. Materials Exploration and Testing. All discussion of field investigation procedures, including exploratory investigation of strength, and of laboratory index properties tests given in Tables 6-2, 6-3, 6-4, and 6-5 is applicable to the characterization of potential embankment materials. The objective is to develop sufficient information regarding the various sources of fill material for a comparison among feasible alternatives.

6-4. Embankment Design Considerations. The development of an investigation for the dike foundation and for proposed borrow areas, the selection of a foundation preparation method, and the design of the embankment cross section require specialized knowledge in soil mechanics. Therefore, all designs and specifications should be prepared under the direct supervision and guidance of a geotechnical engineer and should bear his approval.

a. Factors in Design. In addition to the project constraints described in 6-1.c.(1), the site-specific factors that should be considered in the design of containment dikes are foundation conditions; dike stability with respect to shear strength, settlement, seepage, and erosion; available dike materials; and available construction equipment.

b. Dike Geometry. The height and crown width of a dike are primarily dependent on project constraints generally unrelated to stability. Side slopes and materials allocation within the cross section are functions of foundation conditions, materials availability, and time available for construction.

c. Embankment and Foundation Stability. Proposed cross-section designs should be analyzed for stability as it is affected by foundation and/or embankment shear strength, settlement caused by compression of the foundation and/or the embankment, and external erosion. The analytic methods described and referenced herein contain procedures that have proven satisfactory from past use, and most are currently employed by the CE. Specific details concerning methods for analyzing dike stability are reported in TR D-77-9 (item 16) and in EM 1110-2-1902. Several computer programs are available to CE districts to assist in stability analyses, either on mainframe or on microcomputers.

d. Causes of Dike Instability.

(1) Inadequate shear strength. Overstressing of low shear strength soils in the dike and/or the foundation (often coupled with seepage effects) is the cause of most dike failures. Failures of this type can be the most catastrophic and damaging of all since they usually occur quickly and can result in the loss of an entire section of the dike along with the contained dredged material. These failures may involve the dike alone, or they may involve both the dike and the foundation. Thus, two forms of instability may occur:

(a) Where the foundation is much stronger than the embankment, the dike slope can fail in a rotational slide tangent to the firm base as shown in Figure 6-2. However, if a much weaker horizontal plane or layer exists at or near the contact between the dike fill and the foundation, the failure may be a translation type, taking the form of a sliding wedge as shown in Figure 6-3.

(b) When the strength of the foundation is equal to or less than that of the fill, a rotational sliding failure that involves both the fill and the foundation may occur, as shown in Figure 6-4. If the foundation contains one or more weaker horizontal planes or layers, then a translation type failure, in the form of a sliding wedge, may occur as shown in Figure 6-5.

(c) Recommended minimum factors of safety and applicable shear strength tests for slope stability analyses of containment dikes are given in Table 6-6. These values are to be used where reliable subsurface data from a field exploration and laboratory testing program are available for input to a stability analysis. The factors of safety given in Table 6-6 are applicable to dikes less than 30 feet in height where the consequences of failure are not severe. For dikes greater than 30 feet in height and where the consequences of failure are severe, the criteria given in Table 1 of EM 1110-2-1902 should be used.

(d) When the foundation soils are very soft, as is often the case, various design sections are used to provide stability, as shown in Figure 6-6. A floating section may be used, with very flat slopes and often a berm. The settlement of this section may become detrimental. The soft foundation may be displaced by the firmer dike material, or the soft foundation may be removed and replaced with compacted fill.

(2) Seepage. Potentially detrimental seepage can occur through earth dikes and foundations consisting of pervious or semipervious materials unless prevented by positive means such as impervious linings, blankets, or cutoffs. Seepage effects can create instability through internal erosion (piping) of the dike or foundation materials, or they may lead to a shear failure by causing a reduction in the shear strength of the dike and/or foundation materials through increased pore water pressure or by the introduction of seepage forces. The following conditions may create or contribute to seepage problems in containment dikes:

(a) Dikes with steep slopes composed of coarse-grained pervious materials or fine-grained silt. The seepage surface through the embankment may exit on the outer slope above the dike toe, as shown in Figure 6-7, resulting in raveling of the slope. If the dike contains alternating layers of pervious and impervious materials, the seepage surface may even approach a horizontal line near the ponding surface elevation, as shown in Figure 6-8, creating a potentially severe seepage problem.

(b) Dikes built on pervious foundation materials or where pervious materials are near the surface or exposed as a result of nearby excavation. As shown in Figure 6-9, this is a common condition where material adjacent to the dike toe is used for the embankment. This condition may lead to the development of large uplift pressures beneath and at the outer toe of the dike,

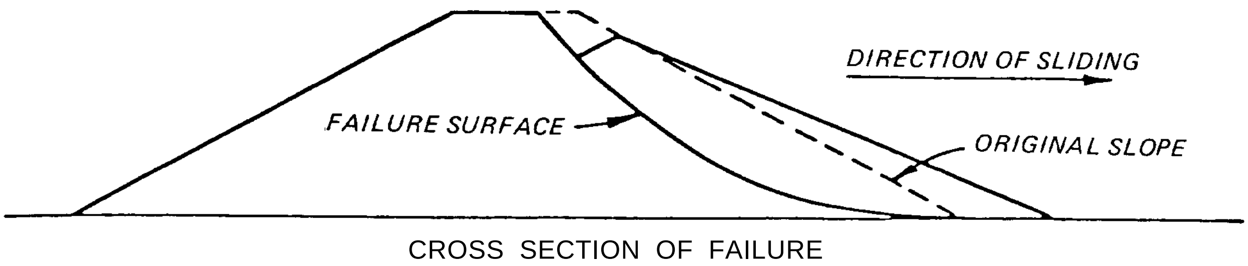


Figure 6-2. Rotational failure in dike

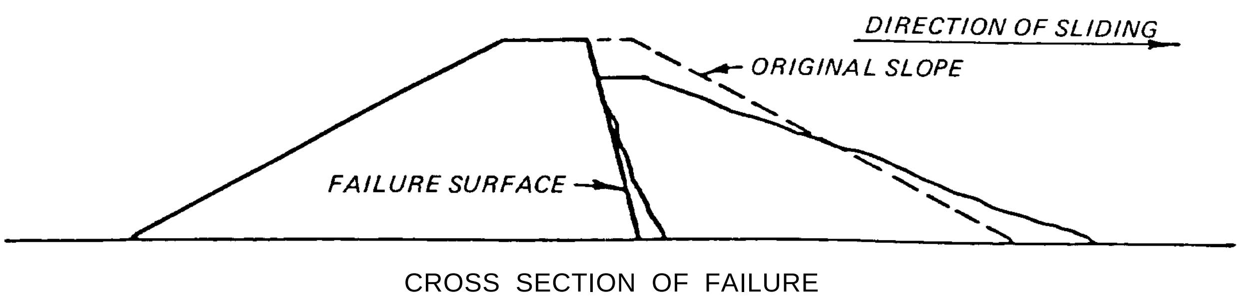


Figure 6-3. Translatory failure in dike

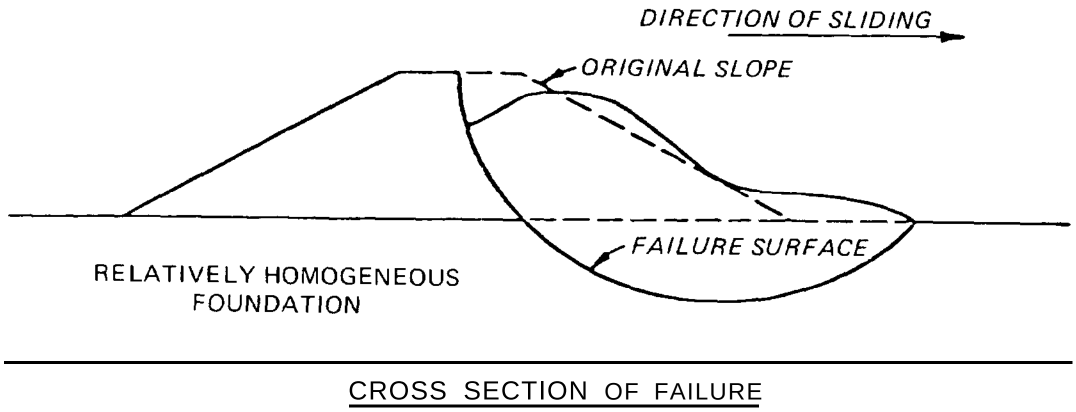


Figure 6-4. Rotational failure in both dike and foundation

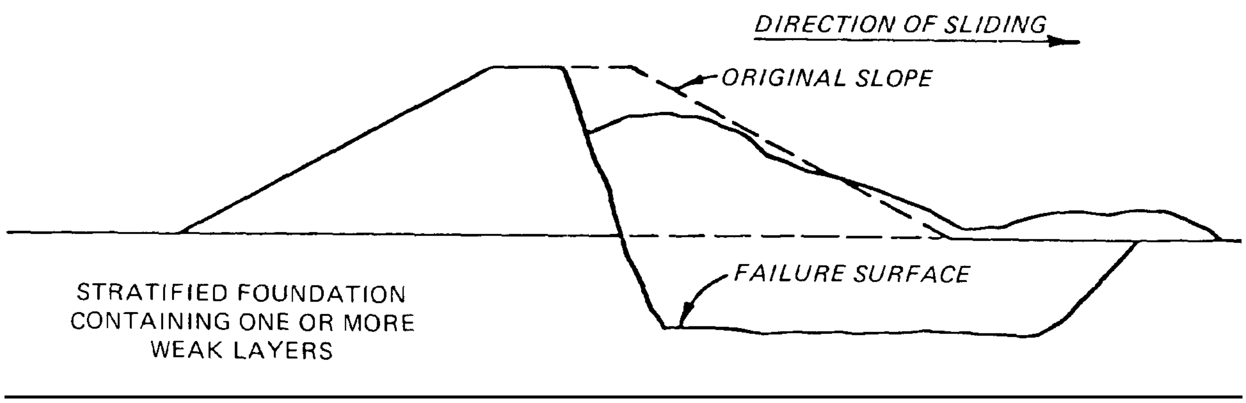


Figure 6-5. Translatory failure in both dike and foundation

Table 6-6
Applicable Shear Strengths and Recommended
Minimum Factors of Safety*

Condition	Shear Strength: Impervious Soils**	Shear Strength: Free-Draining Soils	Slope Analyzed	Minimum Factor of Safety†: Main Dikes	Minimum Factor of Safety†: Appurtenant Dikes
End of construction	Q	S	Exterior and interior	1.3‡	1.3
Steady seepage	Q, R††	S	Exterior	1.3	1.2
Sudden drawdown	Q, R††	S	Exterior	1.0	NA

* Criteria not applicable to dikes greater than 30 feet in height or where the consequences of failure are very severe. For such dikes use criteria given in Table 1 of EM 1110-2-1902.

** For low plasticity silt where consolidation is expected to occur rather quickly, the R strength may be used in lieu of the Q strength.

† To be applied where reliable subsurface data from exploration and testing are available; where assumed values are used, recommended minimum factors of safety should be increased by a minimum of 0.1.

†† Use Q strength where it is anticipated loading condition will occur prior to any significant consolidation taking place; otherwise use R strength.

‡ Use 1.5 where considerable lateral deformation of foundation is expected to occur (usually where foundations consist of soft, high-plasticity clay).

causing overall instability from inadequate shear strength or may result in piping near the embankment base. Methods for analyzing this condition are reported in WES TM 3-424 (item 34).

(c) Dikes constructed by casting methods with little or no compaction. When used with fine-grained soils, this method of construction may leave voids within the dike through which water can flow freely, resulting in piping of dike material.

(d) The existence of seepage paths along the contact between structures touching the dike. This condition can be caused by inadequate compaction of the dike materials, shrinkage of material adjacent to structures, or differential settlement, As in the previous case, piping of the dike material often results in and normally leads to breaching of the dike.

e. Dike Settlement.

(1) Settlement of dikes can result from consolidation of foundation and/or embankment materials, shrinkage of embankment materials, or lateral spreading of the foundation. Like uncontrolled seepage, settlement of a dike can result in failure of the dike, but more likely will serve to precipitate

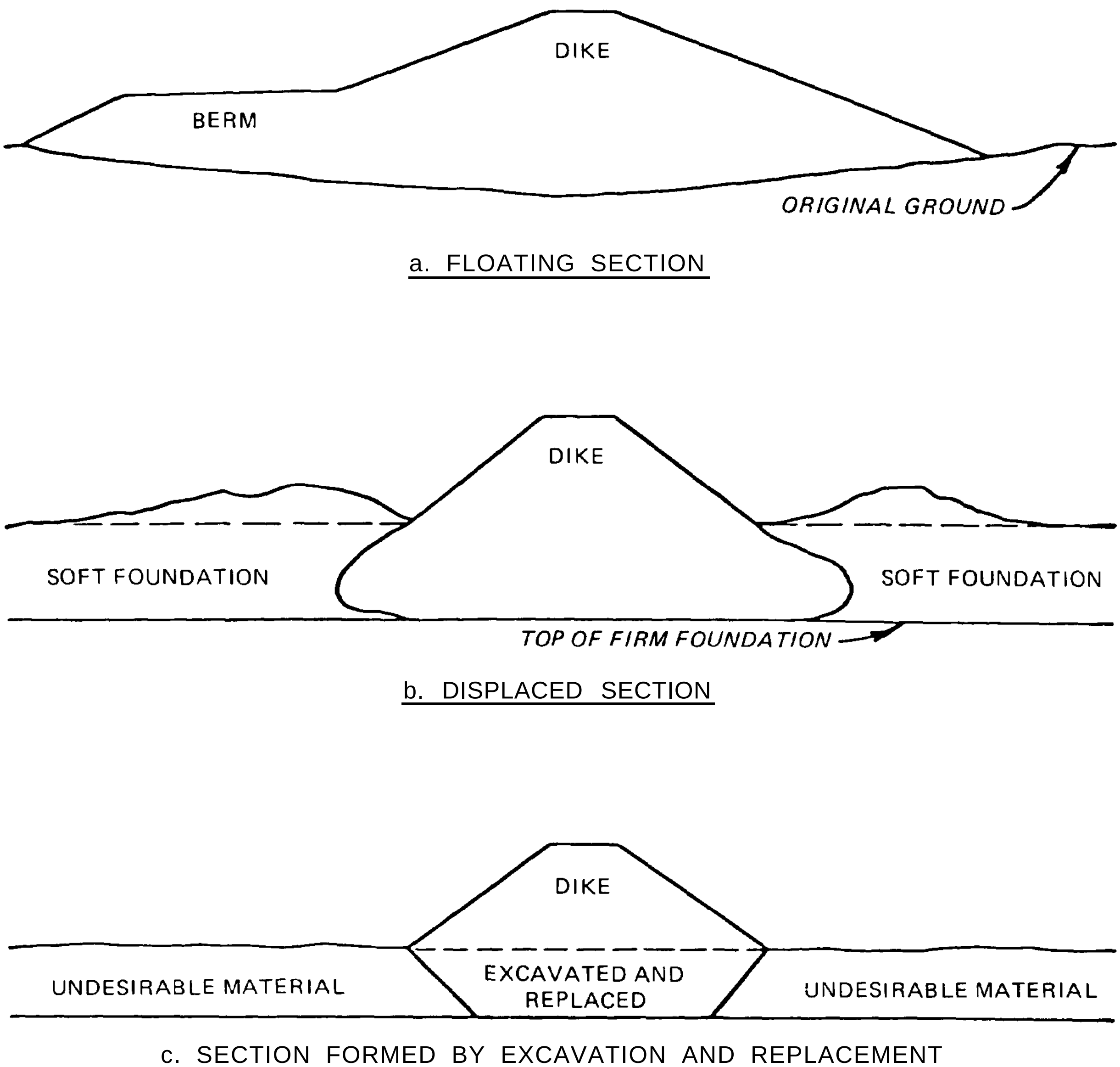


Figure 6-6. Basic methods of forming dike sections for stability

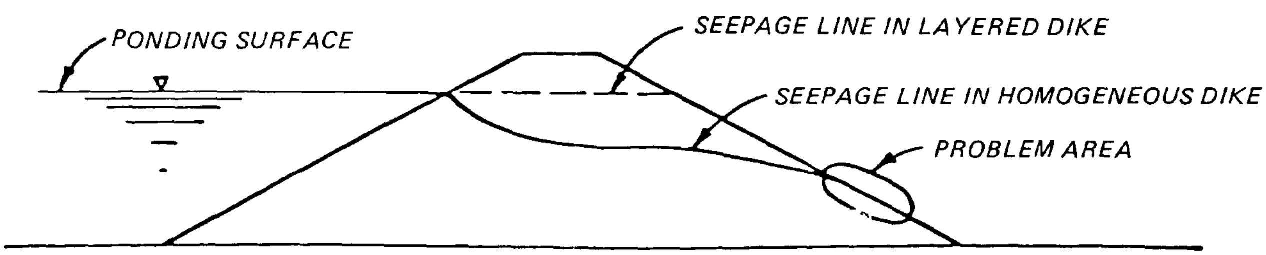


Figure 6-7. Seepage lines through dike

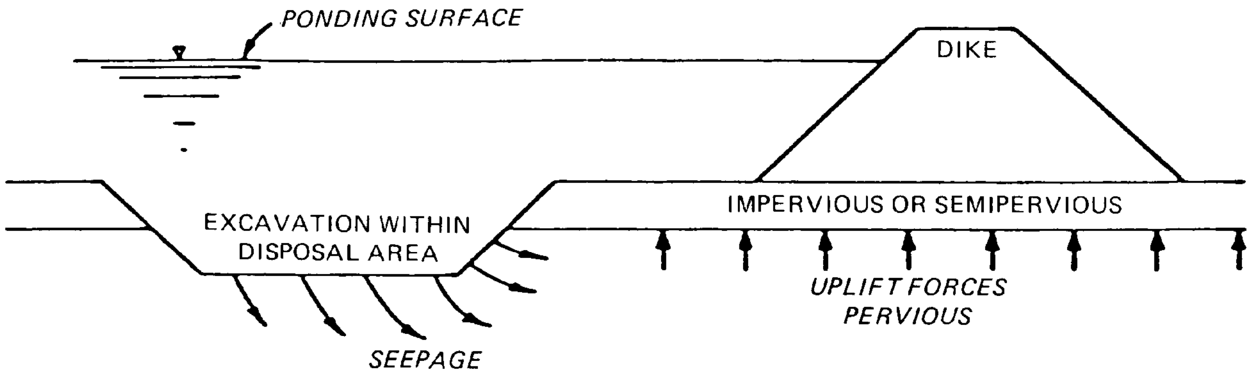


Figure 6-8. Seepage entrance through area excavated within disposal area

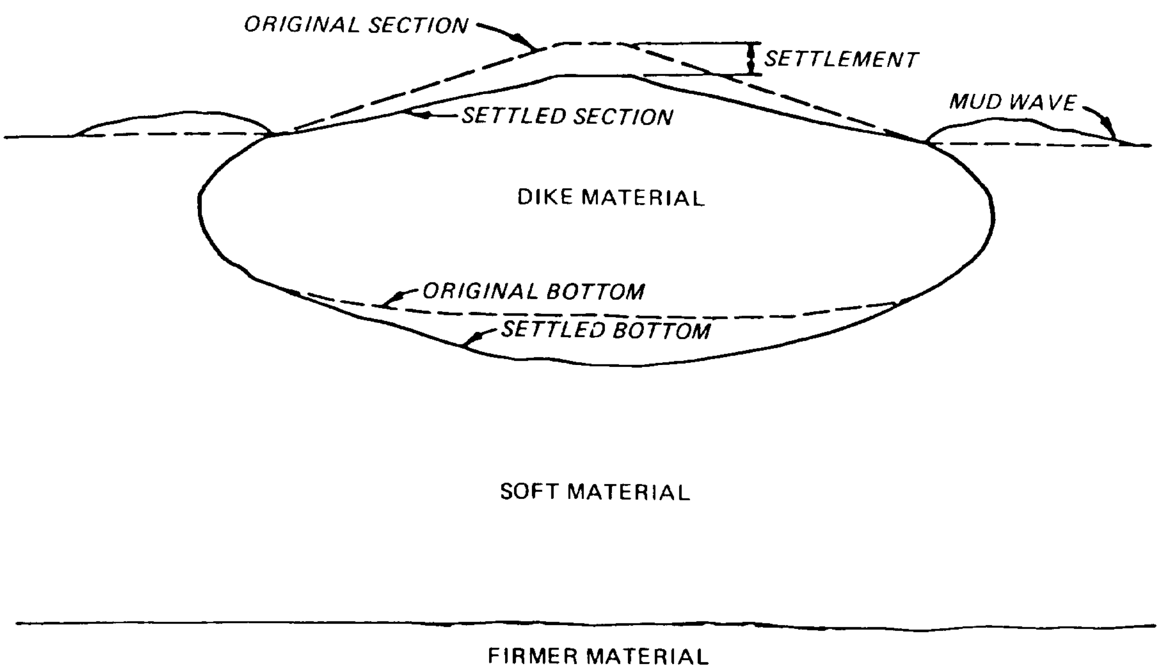


Figure 6-9. Example of excessive uniform settlement

failure by another mode such as seepage or shear failure. Consolidation, shrinkage, and some lateral deformation occur over a period of time, directly related to the soil permeability and the load intensity. Some lateral deformation can occur quickly, however, particularly during construction using the displacement method. Settlement problems are almost always related to fine-grained soils (silts or clays). Settlement and/or shrinkage of coarse-grained soils (sand and gravel) is generally much less than for fine-grained soils and occurs quickly, usually during construction.

(2) Specific forms of settlement that cause problems with dikes include: excessive uniform settlement, differential settlement, shrinkage of uncompacted embankment materials, and settlement resulting from lateral deformation, or creep, of soft foundation soils. Excessive uniform settlement can cause a loss in containment area capacity as a result of the loss of dike

height, as shown in Figure 6-9. Differential settlement can result in cracking of the dike, which can then lead to a shear or piping failure. This is an especially acute problem at the contact between a dike and an adjacent structure. Examples of differential settlement resulting from materials of different compressibility are shown in Figure 6-10. Embankment shrinkage in dikes built with fine-grained soils and placed by means of casting or hydraulic filling can result in volume reductions of as much as 35 percent as a result of evaporation drying.

f. Erosion. Retaining dike failures can be initiated by the effects of wind, rain, waves, and currents that can cause deterioration of exterior and interior dike slopes. The exterior slopes, which are exposed to constant or intermittent wave and/or current action of tidal or flood waters, are usually subject to severe erosion. Interior slopes may also suffer this form of erosion, particularly in large containment areas. The slopes of dikes adjacent to navigable rivers and harbors may be eroded by wave action from passing vessels.

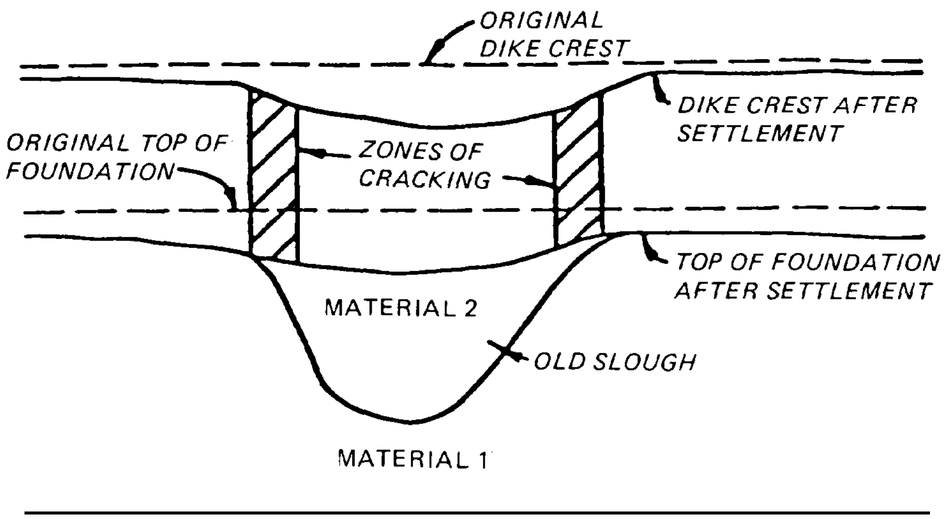
(1) Weathering. Erosion of dike slopes due to the effects of wind, rain, and/or ice is a continuing process. Although these forces are not as immediately severe as wave and current action, they can gradually cause extensive damage to the dike, particularly those dikes formed of fairly clean coarse-grained soils.

(2) Disposal operations. Normal disposal operations can cause erosion of interior dike slopes near the pipeline discharge and/or exterior slopes at the outlet structures. The pipeline discharge of dredged material is a powerful eroding agent, particularly if the flow is not dispersed.

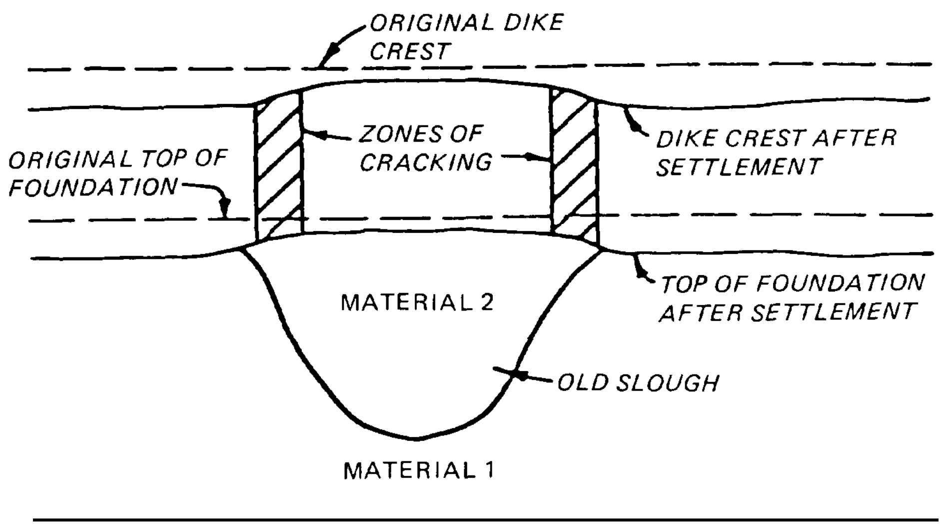
g. Use of geotextiles.

(1) Selection. Geotextiles (permeable textile materials) are being increasingly used in dike construction to provide tensile reinforcement where it will increase the overall strength of the structure. The selection of geotextiles for use in a containment dike is usually based on a substantial cost savings over feasible, practical, alternate solutions, or on the improvement in performance of a design (e.g., more effective installation, reduced maintenance, or increased life).

(2) Stability analyses with geotextile reinforcement. Although the use of a geotextile as reinforcement introduces a complex factor into stability analyses, no specific analytic technique has yet been developed. Therefore, the conventional limited equilibrium-type analyses for bearing capacity and slope stability are used for the design of geotextile reinforced dikes. The bearing capacity analysis, as given in EM 1110-2-1903, assumes the dike to be an infinitely long strip footing. Slope stability analyses, as described in EM 1110-2-1902, involve calculations for stability of a series of assumed sliding surfaces in which the reinforcement acts as a horizontal force to increase the resisting moment. Potential failure modes for fabric-reinforced dike sections are shown in Figure 6-11. Examples of stability analyses for geotextile reinforced embankments are given in item 10.

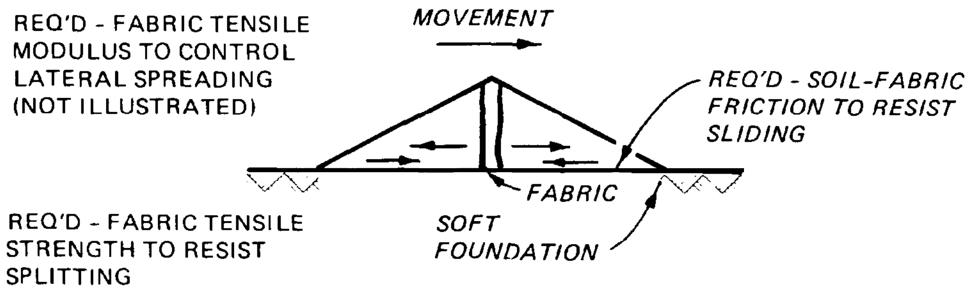


a. COMPRESSIBILITY OF MATERIAL 2 >> MATERIAL 1

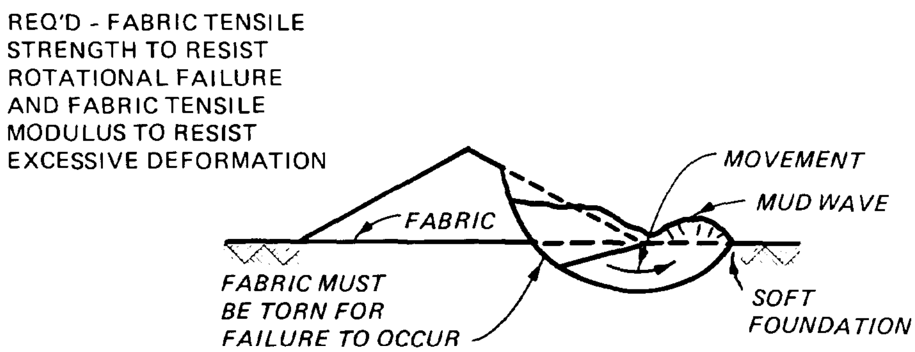


b. COMPRESSIBILITY OF MATERIAL 2 << MATERIAL 1

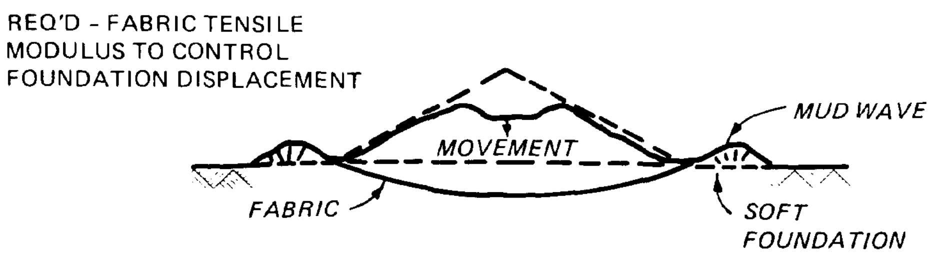
Figure 6-10. Differential settlement from foundation containing materials of different compressibility



A. POTENTIAL EMBANKMENT FAILURE FROM LATERAL EARTH PRESSURE



B. POTENTIAL EMBANKMENT ROTATIONAL SLOPE/FOUNDATION FAILURE



C. POTENTIAL EMBANKMENT FAILURE FROM EXCESSIVE DISPLACEMENT

Figure 6-11. Potential fabric-reinforced embankment failure modes

h. Raising of existing dikes. The height to which a dike can be placed in one stage is sometimes limited by the weakness of the foundation. This limits the capacity of the containment area. The loading of the foundation due to the dike and/or dredged material causes consolidation, and consequent strength gain, of the foundation materials over a period of time. Thus, it is often possible to raise the elevation of an existing dike after some time. Construction of dikes in increments is usually accomplished by incorporating the initial dike into the subsequent dike, as shown in Figure 6-12a, or by constructing them on the dredged fill, at some distance from the inside toe of the existing dike, as shown in Figure 6-12b.

6-5. Construction Equipment.

a. Equipment Types. Types of equipment commonly used in dike construction are listed in Table 6-7 according to the operation they perform. Some types of equipment are capable of performing more than one task, with varying degrees of success. Most of the equipment listed is commonly used in earthwork construction. However, because many dikes are founded on soft to very soft ground, low-ground-pressure versions of the equipment must usually be used in those areas. Specific information on general construction equipment may be found in EM 1110-2-1911. Guidance on equipment available for use on soft soils is given in item 16 and item 13 and on dredging equipment in item 21.

b. Selection Criteria. In the selection of equipment for any particular task, consideration should be given to the following:

(1) Quantity of soil to be excavated, moved, or compacted.

(2) Type of soil to be excavated, moved, or compacted.

(3) Consistency of soils to be excavated, moved, or compacted.

(4) Distance soil must be moved.

(5) Trafficability of soils in borrow, transport, and dike placement areas.

(6) Availability of equipment to fit project time schedule.

(7) Purchase and operating costs.

(8) Auxiliary tasks or uses for equipment.

(9) Maintenance needs; availability of parts.

(10) Standby or backup equipment needs.

(11) Time available for construction of dike.

(12) Money available for construction of dike.

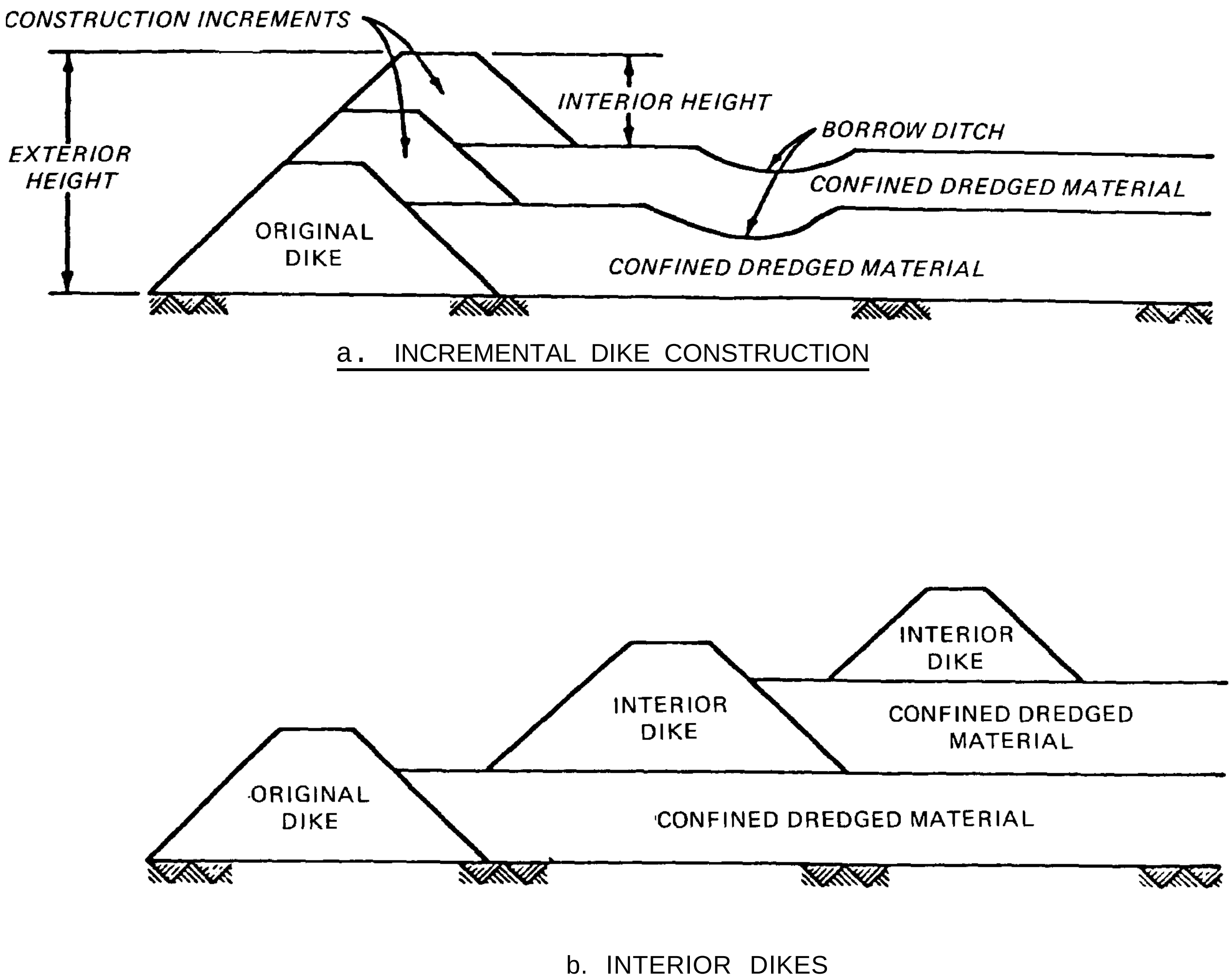


Figure 6-12. Dike raising methods

6-6. Dike Construction. The general construction sequence for a containment dike is normally foundation preparation, borrow area operations, transportation and placement of the dike materials in the embankment, and manipulation and possibly compaction of the materials to the final form and shape.

a. Factors in Method of Construction. The choice of construction method for a containment dike will be governed by available embankment materials, foundation conditions, trafficability of haul roads and the foundation, availability of construction equipment, and project economics.

b. Foundation Preparation. The preparation of a dike foundation usually involves clearing, grubbing, and stripping. Some degree of foundation preparation is desirable to help ensure the integrity of the structure. Clearing and grubbing should be a minimum treatment for all projects. However, in marshy areas where a surface mat of marsh grass and roots exists over a typical soft clay layer, experience has shown that it is often more beneficial from a stability and construction standpoint to leave the mat in place rather

Table 6-7
Equipment Commonly Used in Dike Construction

Operation	Equipment	Application
Excavation	Scraper	Firm to stiff soils; firm roadway
	Dragline	Soft soils that cannot support scrapers
	Dredge	Granular or soft soils below water
Transportation	Scraper	Hauling firm, moist soils
	Truck	Hauling firm, moist soils
	Dragline	Casting soft, wet soils
	Dredge	Pumping soils from below water
Scarification	Disc	Scarifying surface of compacted soil
Spreading	Scraper	Haul and spread from same machine
	Grader	Spread truck-hauled soils
	Crawler dozer	Used on soft terrain
Compaction	Sheepsfoot roller	Clays, silts, clayey or silty sands
	Pneumatic roller	Clays, silts, clayey or silty sands
	Vibratory roller	Clean sand; less than 10% fines
	Crawler tractor	All soils for semicompaction
	Hauling equipment	All soils for semicompaction
Shaping	Grader	Firm to stiff soils
	Crawler dozer	All soils; useful on soft soils
	Dragline	Rough shaping in very soft soils

than remove it, even though this will leave a highly pervious layer under the dike.

(1) Clearing. Clearing consists of the complete removal of all above-ground matter that may interfere with the construction and/or integrity of the dike. This includes trees, fallen timber, brush, vegetation, abandoned structures, and similar debris. Clearing should be accomplished well in advance of subsequent construction operations.

(2) Grubbing. Grubbing consists of the removal of below ground matter that may interfere with the construction and/or integrity of the dike. This includes stumps, roots, buried logs, and other objectionable matter. All holes and/or depressions caused by grubbing operations should have their sides flattened and should be backfilled to foundation grade in the same manner proposed for the embankment filling.

(3) Stripping. After clearing and grubbing, the dike area is usually stripped to remove low-growing vegetation and the organic topsoil layer. This will permit bonding of the fill soil with the foundation, eliminate a soft, weak layer that may serve as a translation failure plane, and eliminate a potential seepage plane. Stripping is normally limited to the dike location

proper and is not usually necessary under stability berms. All stripped material suitable for use as topsoil should be stockpiled for later use on dike and/or borrow area slopes. Stripping is not normally required for dikes on soft, wet foundations or for dikes built by other then full compaction.

(4) Disposal of debris. Debris from clearing, grubbing, and stripping operations can be disposed of by burning in areas where permitted. Where burning is not feasible, disposal is usually accomplished by burial in suitable areas such as old sloughs, ditches, and depressions outside the embankment limits (but never within the embankment proper). Debris should never be placed in locations where it may be carried away by streamflow or where it may block drainage of an area. Material buried within the containment area must be placed so that no debris may escape and damage or block the outlet structure. All buried debris should be covered by a minimum of 3 feet of earth.

(5) Foundation scarification. For compacted dikes on firm foundations only, the prepared foundation should be thoroughly scarified to provide a good bond with the embankment fill.

c. Borrow Area Operations. Factors that should be considered in the planning and operation of a borrow area are site preparation, excavation, drainage, and environmental considerations.

(1) Site preparation. The preparation of the surface of a borrow area includes clearing, grubbing, and stripping. The purpose of this effort is to obtain fill material free from such objectionable matter as trees, brush, vegetation, stumps, roots, and organic soil. In marshy areas, a considerable depth of stripping may be required due to frequently occurring 3- to 4-foot root mats, peat, and underlying highly organic soil. Often, marshy areas will not support the construction equipment. All stripped organic material should be wasted in low areas or, where useable as topsoil, stockpiled for later placement on outer dike slopes, berms, exposed borrow slopes, or other areas where vegetative growth is desired.

(2) Excavation. Planning for excavation operations in borrow areas should give consideration to the proximity of the areas to the dike, topography, location of ground-water table, possible excavation methods and equipment, and surface drainage.

(3) Drainage. Drainage of borrow areas (including control of surface and ground water) is needed to achieve a satisfactory degree of use. Often, natural drainage is poor, and the only choice is to start at the lowest point and work toward the higher areas, thereby creating a sump. Ditches are often effective in shallow borrow areas. Ditching should be done in advance of the excavation, particularly in fine-grained soils, to allow maximum drying of the soils prior to excavation.

(4) Environmental considerations. Permanently exposed borrow areas are usually surface treated to satisfy aesthetic and environmental protection considerations. Generally, projects near heavily populated or industrial areas will require more elaborate treatment than those in sparsely populated areas. Minimum treatment should include topographic shaping to achieve adequate drainage, smoothing and blending of the surface, treatment of the surface to

promote vegetation growth, and placement of vegetation to conform to the surrounding landscape. Item 23 should be consulted for more detailed information concerning landscaping methods.

d. Transportation and Placement of Materials. Three basic methods for transporting and placing dike materials in the embankment are hauling by means of trucks or scrapers, casting by means of a dragline, and pumping, or hydraulic filling, using a dredge. The relative advantages and disadvantages of these methods are summarized in Table 6-8.

e. Manipulation, Compaction, and Shaping. After placement, the dike materials may be compacted, semicompacted, or uncompacted. Many variations and combinations of these methods can and have been used. Classification by these methods does not necessarily refer to the end quality of the embankment; rather it refers to the amount of control of water content and compactive effort used during construction. The relative advantages and disadvantages of the methods of compaction are summarized in Table 6-9.

f. Construction Quality Control. The control of quality of construction operations is an extremely important facet of dike operations. Some of the more pertinent items to be inspected during construction of the dike are given in Table 6-10. For further guidance on control of earthwork operations, see EM 1110-2-1911.

6-7. Miscellaneous Features.

a. Discharge Facilities. Both excessive uniform and differential settlement of the dike can cause distortion and/or rupture of weir discharge pipes located under or through dikes (Figure 6-13) and can cause distortion of the weir box itself (Figure 6-14). The settlement effect can be somewhat mitigated by cambering (Figure 6-15) or raising one end (Figure 6-16) of the pipe during construction.

b. Seepage Control. Antiseepage devices, either metal fins or concrete collars, have been used in the past to inhibit seepage and piping along the outside wall of the outlet pipe. These have not proven effective. To aid in the prevention of piping failures along the pipe-soil interface, an 18-inch-minimum annular thickness of drain material (clean, pervious sand, or sand/gravel) should be provided around the outlet one-third of the pipe, as shown in Figure 6-17. This may be omitted where the outlet one-third of the pipe is located in sand.

c. Additional Uses of Geotextiles. The use of geotextiles to provide soil reinforcement was presented in section 6-4.g. In addition, geotextiles have been extensively used as filter fabrics to replace the filter materials (section 6-7.b.), drain materials, a separation medium, and an armor medium to inhibit erosion item 10. A brief summary of geotextile functions in dike construction is given in Table 6-11.

Table 6-8
Commonly Used Methods of Transporting Soils
in Dike Construction

Method	Advantages	Disadvantages
Hauling	May use central borrow area Permits use of high-speed, high-capacity equipment Allows better selection of soil type	All traveled surfaces must be firm to support equipment Cannot be used in soft, wet areas or underwater May require specialized low-pressure equipment
Casting	Dragline bucket can move very soft, wet soils Can operate on soft foundation	Low speed; low capacity Requires frequent movement of dragline equipment Short casting distance
Dredging	Move large quantities of soils from below water Permits use of dredged materials in dike May be used on soft foundation and roadway	Requires dredge and pipeline Soils cannot be compacted without drying; requires large sections with very flat slopes

Table 6-9
Commonly Used Methods of Compacting Soils
in Dike Construction

Method	Advantages	Disadvantages
Compacted	Placed in thin layers and well compacted, strong dike, low compressibility Steep slopes, minimum space occupied Highest quality control	Requires that soils be dried to water content near plastic limit Requires competent foundation Highest cost
Semicompacted	Uses soils at natural water content, no drying needed May be used on weaker foundations Uses thick lifts May be hauled or cast	Requires flatter slopes May be limited in height Poorer quality control May require specialized low-pressure equipment
Uncompacted	Permits use of cast or dredged materials May be placed on very soft, wet foundation Fill placed at natural water content Lowest cost for dike	Requires very flat slopes May be severely limited in height or require stage construction Poorest quality control

Table 6-10
Operations or Items to Be Inspected During
Construction of Dikes

Type Construction	Items or Operation to Be Checked
Compacted	Proper fill material Loose lift thickness Disking Water content Type of compaction equipment and number of passes Density
Semicompacted	Proper fill material Loose lift thickness Water content (if required) Number of passes (if required) Routing of hauling and spreading equipment
Uncompacted (displacement technique)	Proper fill material Dumping and shoving techniques Ensuring fill is advanced in V-shape and with slopes as steep as possible Elevation of fill surface Prevention of rutting of fill surface by hauling equipment

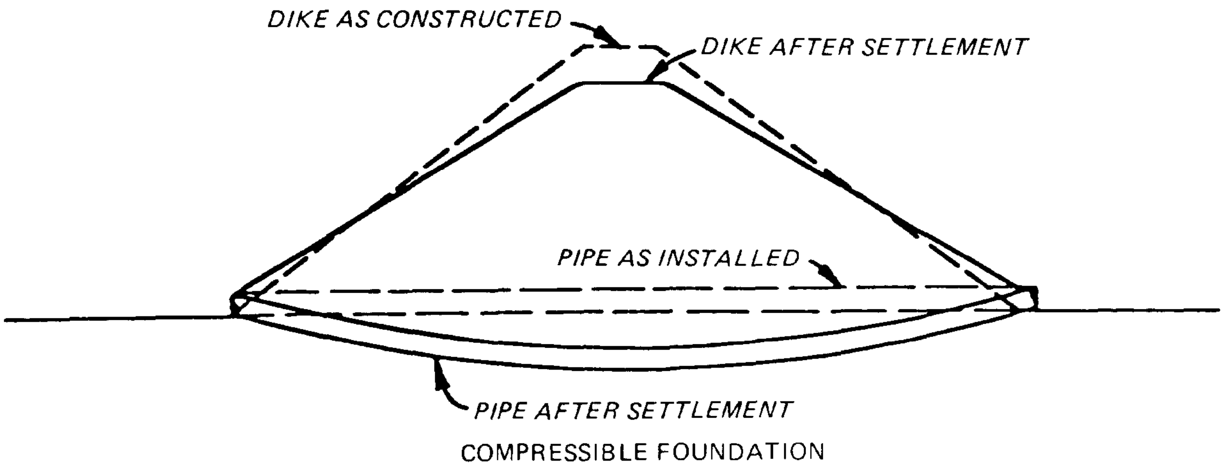


Figure 6-13. Swagging of pipe due to settlement of dike and foundation

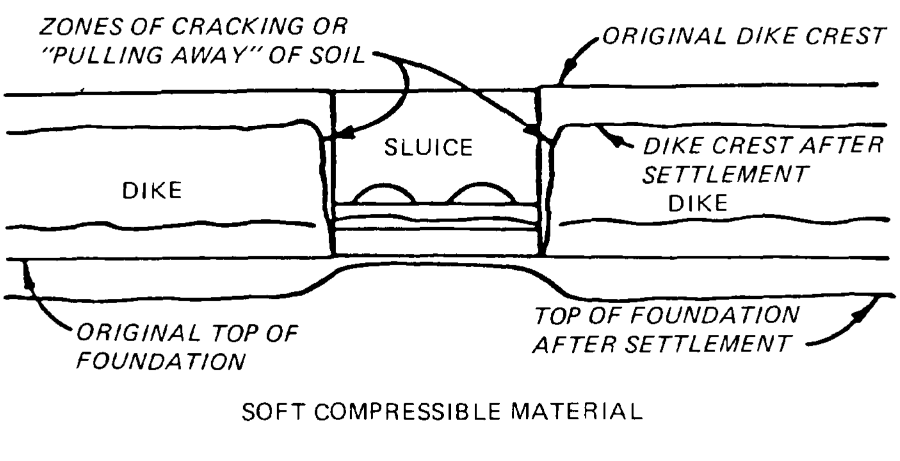


Figure 6-14. Cracking at dike-structure junction caused by differential settlement because dike load is much greater than weir load

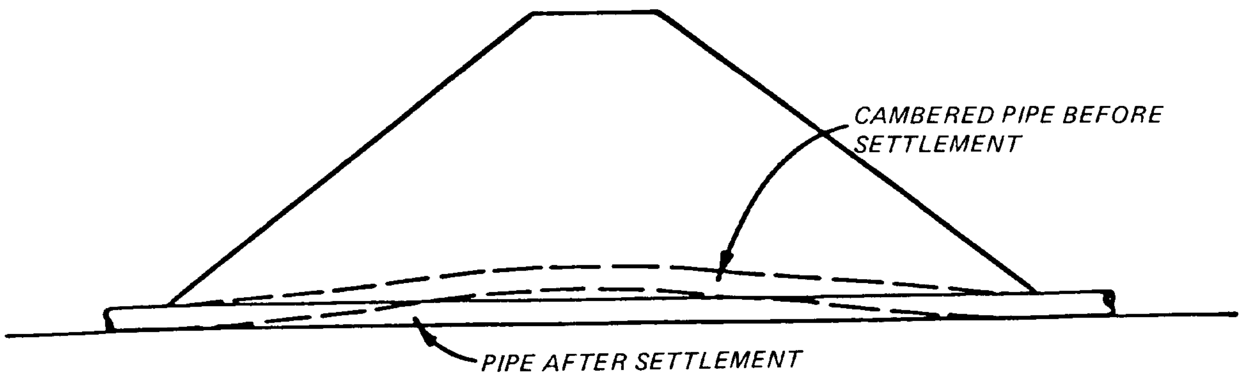


Figure 6-15. Cambered pipe beneath dike

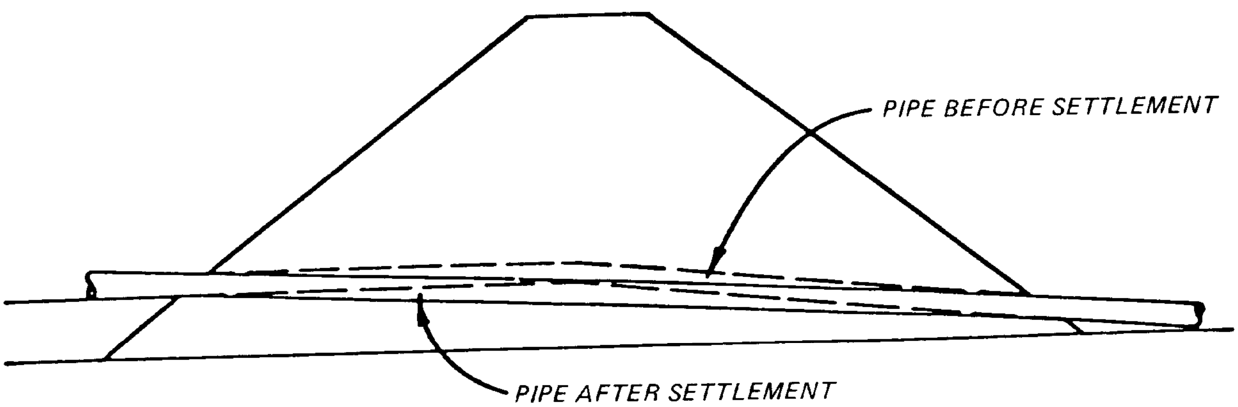
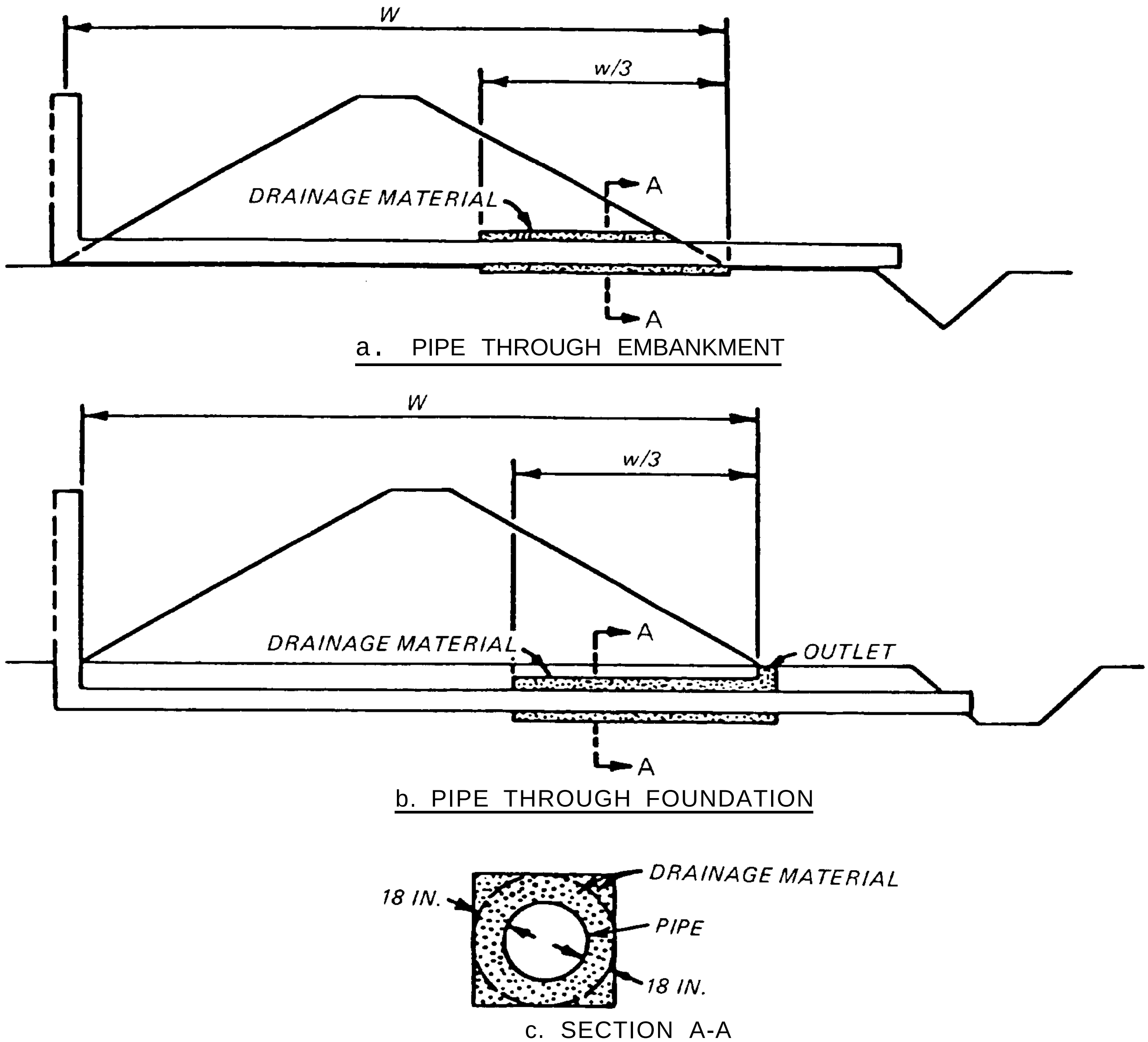


Figure 6-16. Cambered and raised pipe beneath dike



NOTE: W = SECTION WIDTH

Figure 6-17. Annular drainage material around outlet one third of pipe

Table 6-11
Description of Geotextile Functions

Function	Description
Filter	The process of allowing water to escape easily from a soil unit while retaining the soil in place. The water is carried away by some other drain (e.g., rock or rock with pipe).
Drain	The situation where the fabric itself is to carry the water away from the soil to be drained.
Separation	The process of preventing two dissimilar materials from mixing. This is distinct from the filtration function, in that it is not necessary for water to pass through the fabric.
Reinforcement	The process of adding mechanical strength to the soil-fabric system.
Armor	The process of protecting the soil from surface erosion by some tractive force. Usually in these situations, the fabric serves only for a limited time.