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Chapter 7 Levee Construction

Section I *Levee Construction Methods*

7-1. Classification of Methods

a. Levee embankments classified according to construction methods used are listed in Table 7-1 for levees composed of impervious and semipervious materials (i.e., those materials whose compaction characteristics are such as to produce a well-defined maximum density at a specific optimum water content). While the central portion of the embankment may be Category I (compacted) or II (semicompacted), riverside and landside berms (for seepage or stability purposes) may be constructed by Category II or III (uncompacted) methods.

b. Pervious levee fill consisting of sands or sands and gravels may be placed either in the dry with normal earthmoving equipment or by hydraulic fill methods. Except in seismically active areas or other areas requiring a high degree of compaction, compaction by vibratory means other than that afforded by tracked bulldozers is not generally necessary. Where underwater placement is required, it can best be accomplished with pervious fill using end-dumping, dragline, or hydraulic means, although fine-grained fill can be so placed if due consideration is given to the low density and strength obtained using such materials.

Section II *Foundations*

7-2. Foundation Preparation and Treatment

a. General. Minimum foundation preparation for levees consists of clearing and grubbing, and most levees will also require some degree of stripping. Clearing, grubbing, stripping, the disposal of products therefrom, and final preparation are discussed in the following paragraphs.

b. Clearing. Clearing consists of complete removal of all objectional and/or obstructive matter above the ground surface. This includes all trees, fallen timber, brush, vegetation, loose stone, abandoned structures, fencing, and similar debris. The entire foundation area under the levee and berms should be cleared well ahead of any following construction operations.

c. Grubbing. Grubbing consists of the removal, within the levee foundation area, of all stumps, roots, buried logs, old piling, old paving, drains, and other objectional matter. Grubbing is usually not necessary beneath stability berms. Roots or other intrusions over 38.1 mm (1-1/2 in.) in diameter within the levee foundation area should be removed to a depth of 0.91 m (3 ft) below natural ground surface. Shallow tile drains sometimes found in agricultural areas should be removed from the levee foundation area. The sides of all holes and depressions caused by grubbing operations should be flattened before backfilling. Backfill, consisting of material similar to adjoining soils, should be placed in layers up to the final foundation grade and compacted to a density equal to the adjoining undisturbed material. This will avoid "soft spots" under the levee and maintain the continuity of the natural blanket.

d. Stripping. After foundation clearing and grubbing operations are complete, stripping is commenced. The purpose of stripping is to remove low growing vegetation and organic topsoil. The depth of stripping

**Table 7-1
Classification According to Construction Method of Levees Composed of Impervious and Semipervious Materials**

Category	Construction Method	Use
I. Compacted	<p>Specification of:</p> <ul style="list-style-type: none"> a. Water content range with respect to standard effort optimum water content b. Loose lift thickness (152.4 mm to 228.6 mm (6-9 in.)) c. Compaction equipment (sheepsfoot or rubber-tired rollers) d. Number of passes to attain a given percent compaction based on standard maximum density e. Minimum required density 	<p>Provides embankment section occupying minimum space. Provides strong embankments of low compressibility needed adjacent to concrete structures or forming parts of highway systems.</p> <p>Requires strong foundation of low compressibility and availability of borrow materials with natural water contents reasonably close to specified ranges.</p> <p>Used where field inspection is not constant throughout the project.</p>
II. Semicompacted	<p>Compaction of fill materials at their natural water content (i.e., no water content control). Borrow materials known to be too wet would require some drying before placement. Placed in thicker lifts than Category I (about 304.8 mm (12 in.)) and compacted either by controlled movement of hauling and spreading equipment or by fewer passes of sheepsfoot or rubber-tired rollers. Compaction evaluated relative to 15-blow compaction test.</p>	<p>The most common type of levee construction used in reaches where:</p> <ul style="list-style-type: none"> a. There are no severe space limitations and steep-sloped Category I embankments are not required. b. Relatively weak foundations could not support steep-sloped Category I embankments. c. Underseepage conditions are such as to require wider embankment base than is provided by Category I construction. d. Water content of borrow materials or amount of rainfall during construction season is such as not to justify Category I compaction.
III. Uncompacted	<ul style="list-style-type: none"> a. Fill cast or dumped in place in thick layers with little or no spreading or compaction. b. Hydraulic fill by dredge, often from channel excavation. 	<p>Levees infrequently constructed today using methods except for temporary emergency. Both methods are used for construction of stability berms, pit fills and seepage berms.</p>

is determined by local conditions and normally varies from 152.4 to 304.8 mm (6 to 12 in.) Stripping is usually limited to the foundation of the levee embankment proper, not being required under berms. All stripped material suitable for use as topsoil should be stockpiled for later use on the slopes of the embankment and berms. Unsuitable material must be disposed of by methods described in the next paragraph.

e. Disposal of debris. Debris from clearing, grubbing, and stripping operations can be disposed of by burning in areas where this is permitted. When burning is prohibited by local regulations, it needs to be disposed of in an environmentally approved manner.

f. Exploration trench. An exploration trench (often termed “inspection trench”) should be excavated under all levees unless special conditions as discussed later warrant its omission. The purpose of this trench is to expose or intercept any undesirable underground features such as old drain tile, water or sewer lines, animal burrows, buried logs, pockets of unsuitable material, or other debris. The trench should be located at or near the centerline of hauled fill levees or at or near the riverside toe of sand levees so as to connect with waterside impervious facings. Dimensions of the trench will vary with soil conditions and embankment configurations. Backfill should be placed only after a careful inspection of the excavated trench to ensure that seepage channels or undesirable material are not present; if they are, they should be dug out with a base of sufficient width to allow backfill compaction with regular compaction equipment. To backfill narrower trenches properly, special compaction procedures and/or equipment will be required. Trenches should have a minimum depth of 1.83 m (6 ft) except for embankment heights less than 1.83 m (6 ft), in which case the minimum depth should equal the embankment height. Exploration trenches can be omitted where landside toe drains beneath the levee proper constructed to comparable depths are employed (toe drains are discussed in more detail later in this chapter).

g. Dewatering. Dewatering levee foundations for the purpose of excavation and back filling in the dry is expensive if more than simple ditches and sumps are required, and is usually avoided if at all possible. The cost factor may be an overriding consideration in choosing seepage control measures other than a compacted cutoff trench, such as berms, blankets, or relief wells. Where a compacted cutoff trench involving excavation below the water table must be provided, dewatering is essential. TM 5-818-5 provides guidance in dewatering system design.

h. Final foundation preparation. Soft or organic spots in the levee foundation should be removed and replaced with compacted material. Except in special cases where foundation surfaces are adversely affected by remolding (soft foundations for instance), the foundation surface upon or against which fill is to be placed should be thoroughly broken up to a depth of at least 152.4 mm (6 in.) prior to the placement of the first lift of fill. This helps to ensure good bond between the foundation and fill and to eliminate a plane of weakness at the interface. The foundation surface should be kept drained and not scarified until just prior to fill placement in order to avoid saturation from rainfall.

7-3. Methods of Improving Stability

a. General. Levees located on foundation soils that cannot support the levee embankment because of inadequate shear strength require some type of foundation treatment if the levee is to be built. Foundation deposits that are prone to cause problems are broadly classified as follows: (1) very soft clays, (2) sensitive clays, (3) loose sands, (4) natural organic deposits, and (5) debris deposited by man. Very soft clays are susceptible to shear failure, failure by spreading, and excessive settlement. Sometimes soft clay deposits have a zone of stronger clay at the surface, caused by dessication, which if strong enough may eliminate the need for expensive treatment. Sensitive clays are brittle and even though possessing considerable strength in the undisturbed state, are subject to partial or complete loss of strength upon disturbance. Fortunately,

extremely sensitive clays are rare. Loose sands are also sensitive to disturbance and can liquefy and flow when subjected to shock or even shear strains caused by erosion at the toe of slopes. Most organic soils are very compressible and exhibit low shear strength. The physical characteristics and behavior of organic deposits such as peat can sometimes be predicted with some degree of accuracy. Highly fibrous organic soils with water contents of 500 percent or more generally consolidate and gain strength rapidly. The behavior of debris deposited by man, such as industrial and urban refuse, is so varied in character that its physical behavior is difficult, if not impossible, to predict. The following paragraphs discuss methods of dealing with foundations that are inadequate for construction of proposed levees.

b. Excavation and replacement. The most positive method of dealing with excessively compressible and/or weak foundation soils is to remove them and backfill the excavation with suitable compacted material. This procedure is feasible only where deposits of unsuitable material are not excessively deep. Excavation and replacement should be used wherever economically feasible.

c. Displacement by end dumping.

(1) Frequently low levees must be constructed across sloughs and stream channels whose bottoms consist of very soft fine-grained soils (often having high organic content). Although the depths of such deposits may not be large, the cost of removing them may not be justified, as a levee of adequate stability can be obtained by end-dumping fill from one side of the slough or channel, pushing the fill over onto the soft materials, and continually building up the fill until its weight displaces the foundation soils to the sides and front. By continuing this operation, the levee can finally be brought to grade. The fill should be advanced with a V-shaped leading edge so that the center of the fill is most advanced, thereby displacing the soft material to both sides. A wave of displaced foundation material will develop (usually visible) along the sides of the fill and should not be removed. A disadvantage of this method is that all soft material may not be displaced which could result in slides as the embankment is brought up and/or differential settlement after construction. Since this type of construction produces essentially uncompacted fill, the design of the levee section should take this into account.

(2) When this method of foundation treatment is being considered for a long reach of levee over unstable areas such as swamps, the possibility of facilitating displacement by blasting methods should be evaluated. Blasters' Handbook (1966) (Appendix A-2) presents general information on methods of blasting used to displace soft materials.

(3) The end-dumping method is also used to provide a working platform on soft foundation soils upon which construction equipment can operate to construct a low levee. In this case, only enough fill material is hauled in and dozed onto the foundation to build a working platform or pad upon which the levee proper can be built by conventional equipment and methods. Material forming the working platform should not be stockpiled on the platform or a shear failure may result. Only small dozers should be used to spread and work the material. Where the foundation is extremely weak, it may be necessary to use a small clamshell to spread the material by casting it over the area.

d. Stage construction.

(1) General. Stage construction refers to the building of an embankment in stages or intervals of time. This method is used where the strength of the foundation material is inadequate to support the entire weight of the embankment, if built continuously at a pace faster than the foundation material can drain. Using this method, the embankment is built to intermediate grades and allowed to rest for a time before placing more fill. Such rest periods permit dissipation of pore water pressures which results in a gain in strength so that higher embankment loadings may be supported. Obviously this method is appropriate when pore water

pressure dissipation is reasonably rapid because of foundation stratification resulting in shorter drainage paths. This procedure works well for clay deposits interspersed with highly pervious silt or sand seams. However, such seams must have exits for the escaping water otherwise they themselves will become seats of high pore water pressure and low strengths (pressure relief wells can be installed on the landside to increase the efficiency of pervious layers in foundation clays). Initial estimates of the time required for the needed strength gain can be made from results of consolidation tests and study of boring data. Piezometers should be installed during construction to monitor the rate of pore water dissipation, and the resumption and rate of fill placement should be based on these observations, together with direct observations of fill and foundation behavior. Disadvantages of this method are the delays in construction operation, and uncertainty as to its scheduling and efficiency.

(2) Prefabricated vertical (wick) drains. If the expected rate of consolidation under stage construction is unacceptably slow, it may be increased by the use of prefabricated vertical (wick) drains. Such drains are geotextile wrapped plastic cores that provide open flowage areas in the compressible stratum. Their purpose is to reduce the length of drainage paths, thus speeding up primary consolidation. The wick drains are very thin and about 101.6 mm (4 in.) wide. They can be pushed into place through soft soils over 30.5 m (100 ft) deep. Before the drains are installed, a sand drainage blanket is placed on the foundation which serves not only to tie the drains together and provide an exit for escaping pore water, but as a working platform as well. This drainage blanket should not continue across the entire base width of the embankment, but should be interrupted beneath the center.

e. Densification of loose sands. The possibility of liquefaction of loose sand deposits in levee foundations may have to be considered. Since methods for densifying sands, such as vibroflotation, are costly, they are generally not considered except in locations of important structures in a levee system. Therefore, defensive design features in the levee section should be provided, such as wider levee crest, and flatter slopes.

Section III *Embankments*

7-4. Embankment Construction Control

a. Construction control of levees may present somewhat different problems from that of dams because:

(1) Construction operations may be carried on concurrently along many miles of levee, whereas the majority of dams are less than about 0.8 km (0.5 mile) in length and only in a few cases are dams longer than 4.8 km (3 miles). This means that more time is needed to cover the operations on many levee jobs.

(2) While inspection staff and testing facilities are located at the damsite, levee inspection personnel generally operate out of an area office which may be a considerable distance from the levee project.

(3) There are frequently fiscal restraints which prevent assigning an optimum number of inspectors on levee work or even one full-time inspector on small projects. Under these conditions, the inspectors used must be well-trained to observe construction operations, minimizing the number of field density tests in favor of devoting more time to visual observations, simple measurements, and expedient techniques of classifying soils, evaluating the suitability of their water content, observing behavior of construction equipment on the fill, and indirectly assessing compacted field densities.

b. Although it has previously been stated that only limited foundation exploration and embankment design studies are generally needed in areas where levee heights are low and foundation conditions adequate

(i.e., no question of levee stability), the need for careful construction control by competent inspection exists as well as at those reaches where comprehensive investigations and analyses have been made. Some of the things that can happen during construction that can cause failure or distress of even low embankments on good foundations are given in Table 7-2.

Table 7-2
Embankment Construction Deficiencies

Deficiency	Possible Consequences
Organic material not stripped from foundation	Differential settlements; shear failure; internal erosion caused by through seepage
Highly organic or excessively wet or dry fill	Excessive settlements; inadequate strength
Placement of pervious layers extending completely through the embankment	Allows unimpeded through seepage which may lead to internal erosion and failure
Inadequate compaction of embankment (lifts too thick, haphazard coverage by compacting equipment, etc.)	Excessive settlements; inadequate strength; through seepage
Inadequate compaction of backfill around structures in embankment	Excessive settlements; inadequate strength; provides seepage path between structure and material which may lead to internal erosion and failure by piping

7-5. Embankment Zoning

As a general rule levee embankments are constructed as homogeneous sections because zoning is usually neither necessary nor practicable. However, where materials of varying permeabilities are encountered in borrow areas, the more impervious materials should be placed toward the riverside of the embankment and the more pervious material toward the landside slope. Where required to improve underseepage conditions, landside berms should be constructed of the most pervious material available and riverside berms of the more impervious materials. Where impervious materials are scarce, and the major portion of the embankment must be built of pervious material, a central impervious core can be specified or, as is more often done, the riverside slope of the embankment can be covered with a thick layer of impervious material. The latter is generally more economical than a central impervious core and, in most cases, is entirely adequate.

7-6. Protection of Riverside Slopes

a. The protection needed on a riverside slope to withstand the erosional forces of waves and stream currents will vary, depending on a number of factors:

(1) The length of time that floodwaters are expected to act against a levee. If this period is brief, with water levels against the levee continually changing, grass protection may be adequate, but better protection may be required if currents or waves act against the levee over a longer period.

(2) The relative susceptibility of the embankment materials to erosion. Fine-grained soils of low plasticity (or silts) are most erodible, while fat clays are the least erodible.

(3) The riverside slope may be shielded from severe wave attack and currents by timber stands and wide space between the riverbank and the levee.

(4) Structures riverside of the levee. Bridge abutments and piers, gate structures, ramps, and drainage outlets may constrict flow and cause turbulence with resultant scour.

(5) Turbulence and susceptibility to scour may result if levee alignment includes short-radius bends or if smooth transitions are not provided where levees meet high ground or structures.

(6) Requirements for slope protection are reduced when riverside levee slopes are very flat as may be the case for levees on soft foundations. Several types of slope protection have been used including grass cover, gravel, sand-asphalt paving, concrete paving, articulated concrete mat, and riprap, the choice depending upon the degree of protection needed and relative costs of the types providing adequate protection.

b. Performance data on existing slopes under expected conditions as discussed above are invaluable in providing guidance for the selection of the type of slope protection to be used.

c. Sometimes it may be concluded that low cost protection, such as grass cover, will be adequate in general for a levee reach, but with a realization that there may be limited areas where the need for greater protection may develop under infrequent circumstances. If the chances of serious damage to the levee in such areas are remote, good engineering practice would be to provide such increased protection only if and when actual problems develop. Of course, it must be possible to accomplish this expeditiously so that the situation will not get out of hand. In any event, high-class slope protection, such as riprap, articulated mat, or paving should be provided on riverside slopes at the following locations:

(1) Beneath bridges, since adequate turf cannot be generally established because of inadequate sunlight.

(2) Adjacent to structures passing through levee embankments.

d. Riprap is more commonly used than other types of revetments when greater protection than that afforded by grass cover is required because of the relative ease of handling, stockpiling, placement, and maintenance. Guidance on the design of riprap revetment to protect slopes against currents is presented in EM 1110-2-1601. Where slopes are composed of erodible granular soils or fine-grained soils of low plasticity, a bedding layer of sand and gravel or spalls, or plastic filter cloth should be provided beneath the riprap.

e. When suitable rock is not available within economical haul distances, soil cement may provide the most economical slope protection (see Appendix G).