6

Embankment Foundations

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New roads are increasingly being located on poor foundation soils. Thus, comprehensive geotechnical embankment foundation design studies are required to identify and solve potential stability, settlement, and construction problems. The results of these studies are normally incorporated into the construction plans and specifications.

The success of a foundation design is generally judged by embankment performance, although rate and cost of construction may also be important factors. Performance is reflected in pavement rideability, which includes smooth transitions at structures, effects on buried utilities, and frequency of maintenance required during the design life of the roadway. These postconstruction factors are dependent on the amount and rate of settlements, assuming that foundation stability requirements are met satisfactorily during construction. The success of an embankment construction project is directly proportional to the design and construction effort, and it requires good predictions of the behavior of the foundation in response to the applied loads.

With proper specification and construction controls (Chapter 4), incidences of faulty embankment construction are rare. Poor embankment performance is usually a consequence of unexpected variations in subsurface or foundation conditions, inadequate design for site-specific soil conditions, or in cases where a proper foundation design was provided for in the contract documents, lack of strict adherence to the construction specifications.

Project design starts with a preliminary site evaluation. Next, exploratory borings and sampling are conducted, followed by a laboratory testing program, design analyses, and design report. Finally, recommendations for foundation treatment, if any, are incorporated into the contract plans and specifications.

This chapter contains background information on embankment foundation design as it affects construction operations and inspection procedures. Briefly discussed are the several phases of the embankment

*Retired.

foundation design process. Possible treatment alternatives, which may be required for particular problem foundations sites, are also mentioned. Specific problem foundation soils are discussed in Chapter 9.

Good general references to the design and construction of embankment foundations are books by Terzaghi and Peck (1967), Winterkorn and Fang (1975), Cheney and Chassie (1982), and U. S. Navy (1982), as well as other textbooks on foundation engineering. Information on methods of treating problem foundation soils can be found in works by Sinacori et al.(1952), Moore (1966), and Welsh (1987). Also recommended are *NCHRP Syntheses of Highway Practice 2, 8, 27, 33, 89, 107,* and *147.*

DESIGN

Preliminary Data Acquisition Activities

Every subsurface exploration program and subsequent design analysis should be preceded by a site inspection followed by a review of all available information pertinent to the project. The latter includes, for example, data from previous projects in the area, geological and pedological reports and maps, well logs, U. S.Geological Survey maps, aerial photographs, and any existing subsurface exploration data. From this information, such items as old slope failures and landslides, swamps and bogs, different soil types as revealed by landforms, buried stream channels, sinkholes, landfills and dumps, mining activities, and poorly drained areas may be located. All pertinent information should be available to the construction engineer, usually in the project soils report.

Exploration Programs

The boring and sampling requirements for a highway project depend on the size, complexity, and location of the project. Exploratory borings (auger, split spoon), undisturbed sampling for subsequent laboratory testing, or in situ tests may all be used in the boring program. For additional information on this phase of the design process, consult the AASHTO (1988) *Manual on Subsurface Investigations.*

Foundation Design Procedures

Granular soils such as sands and gravels generally provide stable embankment foundations. Settlements on these soils are usually small and occur as the embankment is built.

Soft compressible soils such as clays, organic silts, marls, and peats cause embankment stability and settlement problems. First, a model of the subsurface conditions (soil profile) is established, followed by determinations of the strength and settlement design parameters from interpretations of laboratory test results on undisturbed samples or possibly from in situ tests performed during the subsurface exploration program.

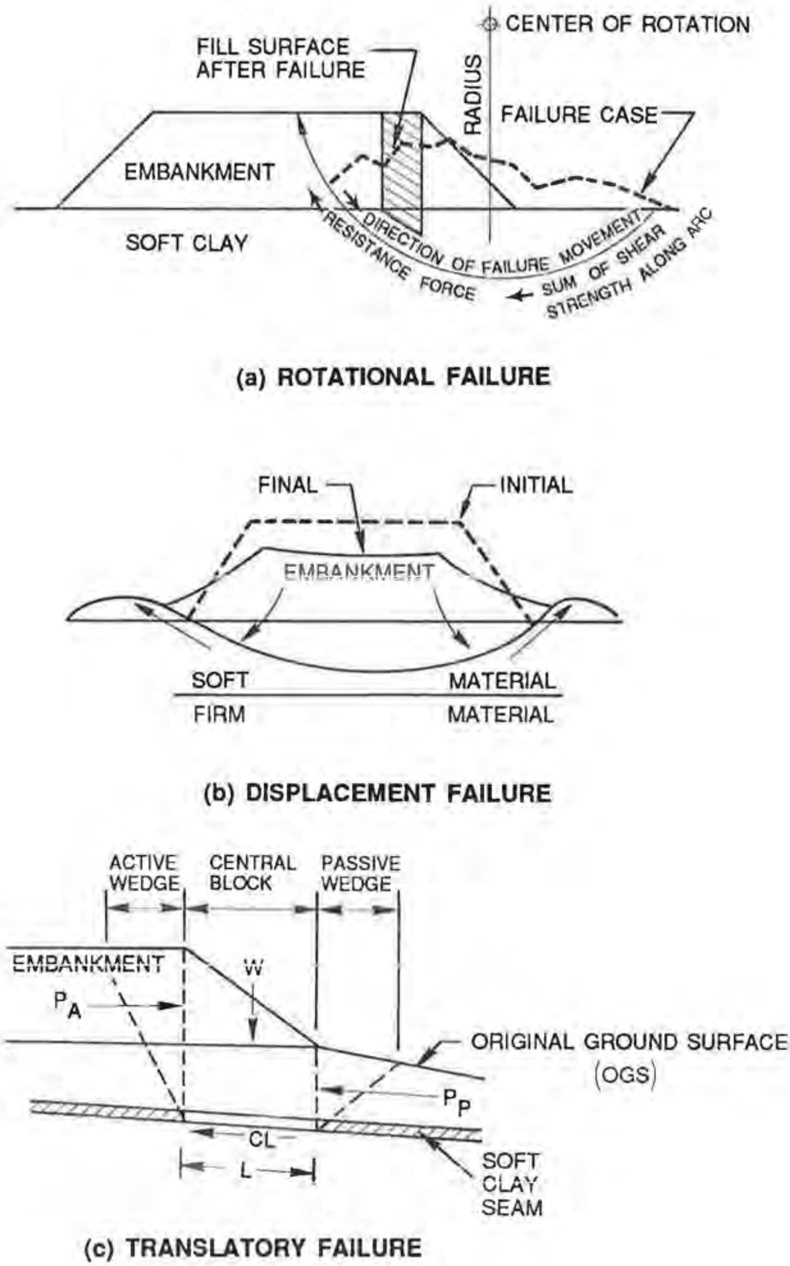
Stability Studies

Failures can occur in situations in which embankments are built on weak soils, such as soft clays, organic silts, and peats, without special foundation treatment. Foundation soils will provide adequate support if the additional stress from the embankment does not exceed the shear strength of any of the underlying strata. Overstressing the foundation soil may result in dramatic embankment failures, which generally occur in one of the ways shown in Figure 6-1. It is important for field engineers to be aware of these possibilities so that should unusual movements appear to be occurring or, for example, cracks start to appear in the embankment, the agency's geotechnical specialist should be contacted immediately. On critical projects or those in which the calculated factor of safety is marginal, the project soils report, or sometimes the project specifications, will state the acceptable limits of settlements or lateral movements of the embankment and foundation. In this case special geotechnical instrumentation (Chapter 10) is used to facilitate these performance observations.

As mentioned earlier, granular foundation soils generally produce small settlements, and because they take place rapidly, usually as the load is placed, they ordinarily pose no particular difficulty in embankment design or construction. On the other hand, foundation soils such as soft clays or organic soils, or both, are capable of large continuous settlements, depending on their geological and loading history and the magnitude of the embankment load. In organic materials especially, settlements may continue almost indefinitely after a project is built. Unusual settlement problems, if anticipated, will be mentioned in the project soils report.

METHODS OF FOUNDATION TREATMENT

If the designer determines that the calculated settlements are too large or that stability problems are likely to arise from construction of the em-



where

P_A = ACTIVE FORCE (Driving) CL = RESISTING FORCE DUE TO COHESION OF CLAY

P_P = PASSIVE FORCE (Resisting) W = WEIGHT OF CENTRAL BLOCK

FIGURE 6-1 Typical embankment failures (*courtesy New York State Department of Transportation.*

bankment, it may be possible to lower the grade or shift the alignment to avoid or minimize potential problems. Stability and settlement problems are often interrelated and time dependent. Finding the most appropriate procedure for ensuring stability and minimizing settlements requires an analysis of various foundation treatment techniques. The two most important factors to consider when selecting a treatment method are economics and construction time, while taking into consideration the sequence of operations and the duration of the contract.

Basically, problem foundation soils can be improved by

1. Reducing the load,
2. Replacing the problem materials with more competent materials,
3. Increasing the shear strength and reducing compressibility of the problem materials,
4. Transferring the loads to more competent layers, and
5. Reinforcing the embankment or its foundation, or both.

For treating problem embankment foundation soils, these general concepts are actually accomplished by the following specific methods: (a) berms or flatter slopes, (b) lightweight fill materials, (c) pile-supported roadways and embankments, (d) removal of soft or problem materials and replacement with suitable fill, (e) stabilization by consolidation of soft foundation materials, (f) chemical alteration/stabilization, (g) physical alteration/stabilization, including densification, and (h) reinforcement. These methods and their variations are listed in Table 6-1. All have been used singly or in combination in the United States, although some methods are much more popular than others, and some have only been used on an experimental basis or for structures other than highway embankments. Variations and combinations of the methods listed in Table 6-1 can be considered applicable, but not necessarily the most economical, for virtually any thickness or type of problem soil.

Berms and Flatter Slopes

Embankment instability in the case of a rotational failure (Figure 6-1a) can be improved by adding a counterweight or stabilizing berm to the lower portion of the embankment (Figure 6-2). Berms often necessitate additional rights-of-way. The berm is normally constructed at the same time as the embankment, not afterward, as has been discovered too late in a few embarrassing cases.

TABLE 6-1 FOUNDATION TREATMENT ALTERNATIVES (Holtz, 1989).

Method	Variations of Method	Generally Applicable to		Is Treatment Generally Time Dependent?		
		Stability Problems	Settlement Problems	Yes	No	Possibly
1. Berms; flatter slopes	—	X	—	—	X	—
2. Reduced stress method	Lightweight fill.	X	X	—	—	X
3. Pile-supported roadway	Elevated structure supported by piles driven into suitable bearing stratum.	X	X	—	X	—
	Swedish method of supporting embankment on piles driven into suitable bearing material. Piles have individual pile caps covering only a portion of base area of fill.	X	X	—	X	—
4. Removal of problem materials and replacement by suitable fill	Complete excavation of problem materials and replacement by suitable fill.	X	X	—	X	—
	Partial excavation (the upper part) of soft material and replacement by suitable fill. No treatment of soft material not removed.	X	X	—	—	X
	Displacement of soft material by embankment weight, assisted by controlled excavation.	X	X	—	X	—
	Displacement of soft material by blasting, augmented by controlled placement of fill.	X	X	—	X	—

5. Stabilization of soft materials by consolidation	Consolidation by surcharge only.	—	X	X	—	—
	Consolidation by surcharge combined with vertical drains to accelerate consolidation.	—	X	X	—	—
	Consolidation by surcharge combined with pressure relief wells or vertical drains along toe of fill.	—	X	X	—	—
6. Consolidation with paving delayed (stage construction)	Before paving, permit consolidation to occur under normal embankment loading without surcharge; accept postconstruction settlements.	—	X	X	—	—
7. Chemical Alteration and Stabilization	Lime and cement columns; grouting and injections; electro-osmosis; thermal; freezing; organic.	X	X	—	—	X
8. Physical alteration and stabilization; densification	Dynamic compaction (heavy tamping); blasting; vibrocompaction and vibroreplacement; sand compaction piles, stone columns; water.	X	X	—	X	—
9. Reinforcement	Geotextiles and geogrids; fascines; Wager short sheet piles; anchors; root piles.	X	—	—	X	—

NOTE: Some combinations of methods are feasible.

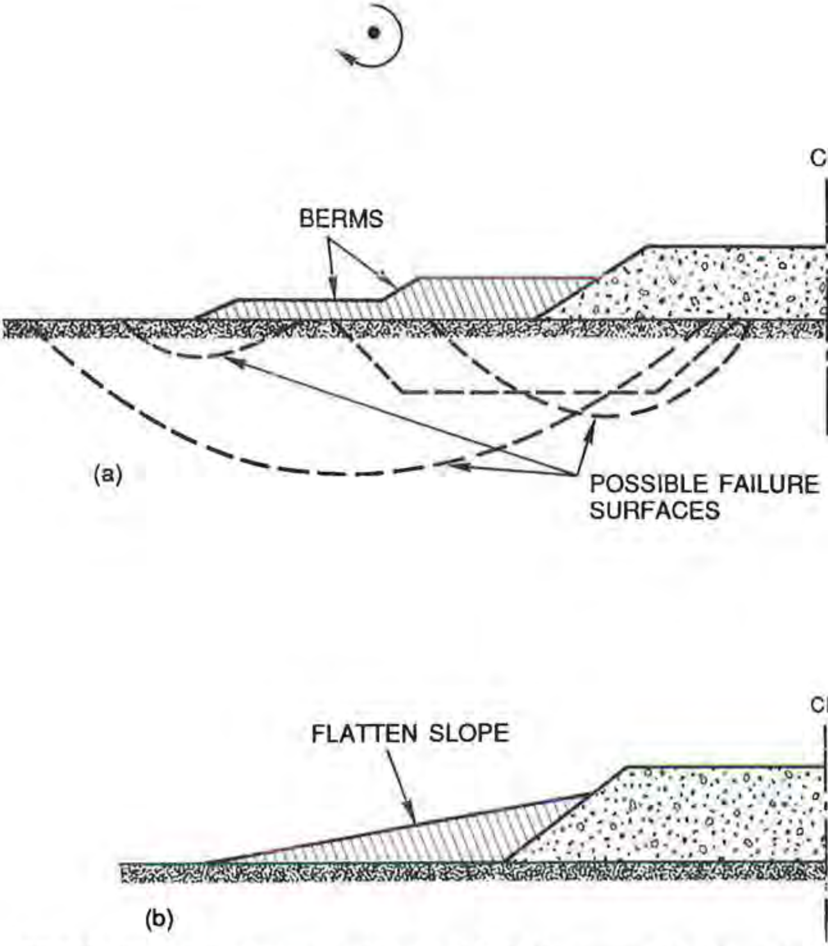


FIGURE 6-2 Embankments stabilized with (a) berms or (b) flatten slopes (*courtesy New York State Department of Transportation*).

Load Reduction

Where the roadway profile cannot be lowered, the use of lightweight embankment fill materials such as cellular concrete, expanded shale, slag, ash, cinders, sawdust and bark, shells, or expanded polystyrene may be considered to reduce the load on the foundation soils (Figure 6-3).

Special construction procedures for placing lightweight fill materials will be given in the special provisions of the project specifications (see Chapter 9, section on Lightweight Fill Materials).

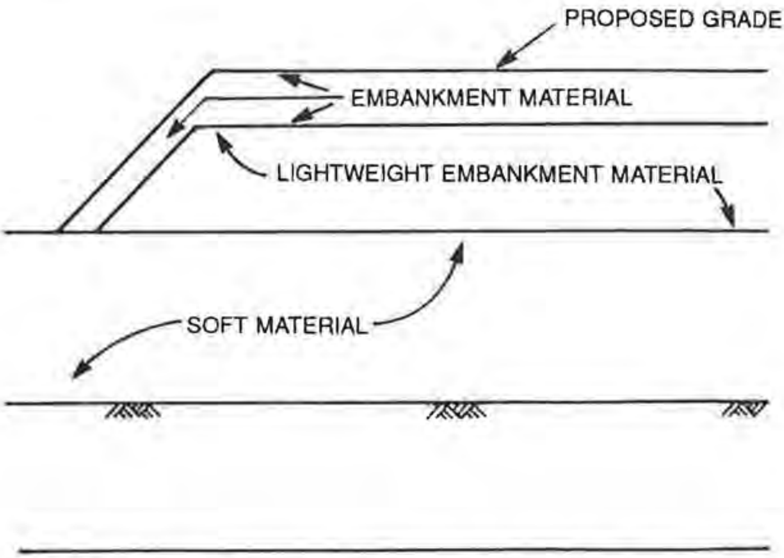


FIGURE 6-3 Use of lightweight embankment fill materials (*courtesy New York State Department of Transportation*).

Pile-Supported Roadways

Pile-supported roadways include elevated structures, such as bridges and viaducts, that are supported by pile foundations and earthen embankments that are supported by relief piles driven to firm bearing layers. The latter system is commonly used to support highway embankments in Scandinavia (Holtz 1989).

Excavation and Replacement

Where feasible, excavation of surface deposits, such as organic material or very soft clay, and replacement with select granular material is an effective means of solving foundation problems. As noted in Table 6-1, the excavation process may be either partial or complete. When the material to be removed is underwater, excavation and backfilling is usually carried out underwater to avoid collapse of the sides of the excavation.

Complete excavation (Figure 6-4) is appropriate where the depth to the bottom of the soft material is fairly shallow, that is, to 20± ft, making removal easy and economical. Partial excavation may be possible in areas where the very soft surface deposit is either quite deep or is underlain by a significantly stronger material. Sometimes the soft materials are displaced by the weight of the fill, as shown in Figure 6-5 (see Chapter 4,

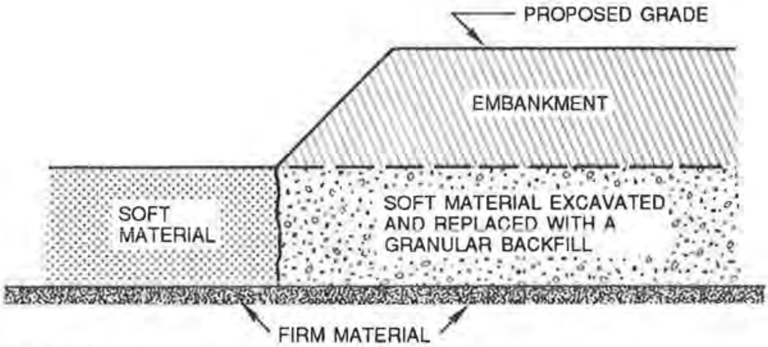


FIGURE 6-4 Complete excavation and replacement.

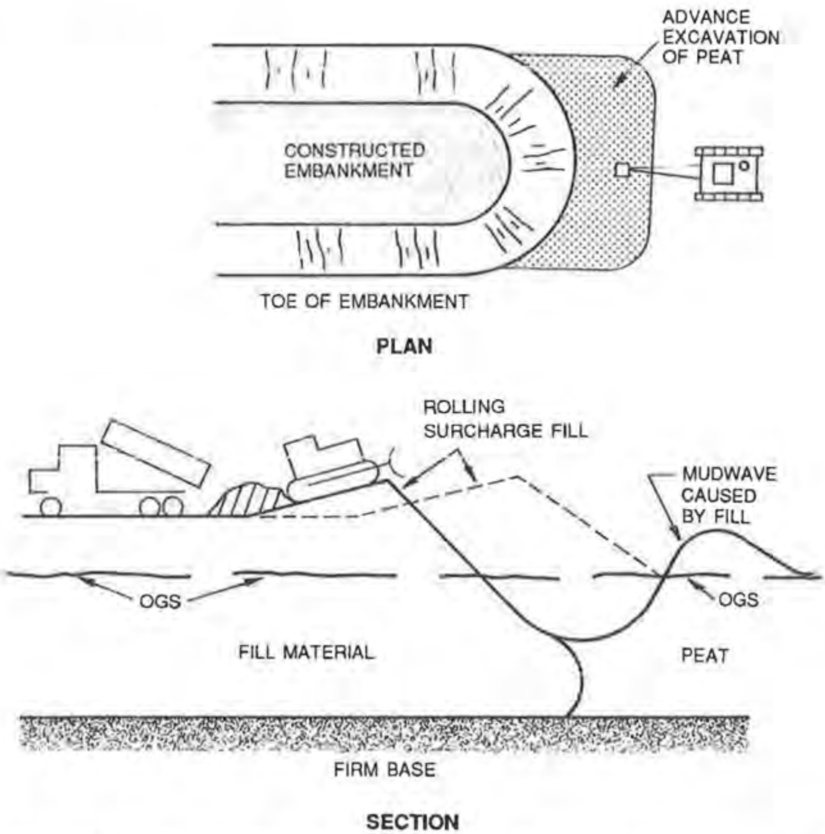


FIGURE 6-5 Gravity displacement method of fill using rolling surcharge and relief excavation at front (MacFarlane 1969; *reprinted with permission from University of Toronto Press*).

section on Unsuitable Materials). All these methods require very careful construction supervision and inspection. Close coordination with the geotechnical specialist is also necessary.

Stabilization by Consolidation

The basic concept of stabilization by consolidation is to force possible detrimental settlements that would otherwise occur after construction to occur during construction when they can be tolerated. This way, corrections can be made before opening the embankment to traffic. A temporary surcharge of additional fill material placed above grade combined with a waiting period causes more settlement in a given time period than would occur without a surcharge. With this procedure, the rate of embankment construction, including surcharge placement, is coordinated so that the surcharge is removed when field settlement and pore pressures equal the predicted values. The criteria given in the project soils report or in the special provisions are ordinarily based on the results of geotechnical instrumentation (Chapter 10) and surveys of line and grade. Although the additional cost of the surcharge fill is usually small, a surcharge may create potential stability problems in very soft foundations. Therefore, modifications in embankment design, such as slope flattening or berms, may also be required, as shown in Figure 6-6.

Also shown in Figure 6-6 are vertical sand drains or prefabricated "wick" drains, which are used to accelerate the consolidation settlements.

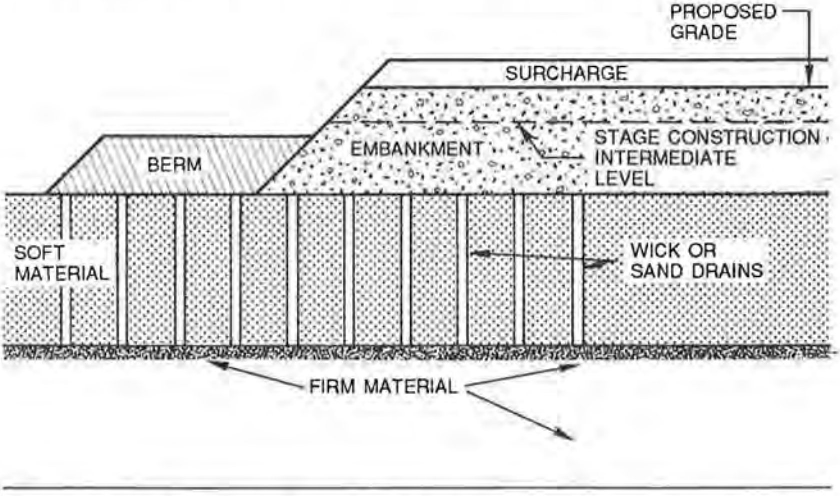


FIGURE 6-6 Stabilization by consolidation with a surcharge fill and wick or sand drains (*courtesy New York State Department of Transportation*).

Because the rate of pore water pressure dissipation increases as the square of the drainage distance decreases, vertical drains installed at typically 5- to 10-ft center-to-center spacings can dramatically reduce the time of consolidation. The corresponding soil strength increase that occurs with consolidation allows the embankment to be safely constructed, frequently in conjunction with stage construction of the fill. Again, these projects usually require monitoring with geotechnical instrumentation (Chapter 10).

Information on prefabricated vertical drains can be found in TRB (1986) Circular 309, and work by Rixner et al. (1986) and Holtz (1987).

Stage Construction with Delayed Paving

With programmed waiting periods between stages, the foundation soils can dissipate excess pore water pressure and settle without surcharge. Field instrumentation (Chapter 10) in the form of piezometers, settlement gauges, and optical survey stakes are required to monitor the foundation performance and regulate waiting periods. Criteria are ordinarily given in the project soils report.

Chemical and Physical Stabilization

Although most chemical and physical techniques have not been extensively utilized in the United States for highway embankments, they may be technically feasible and economical in some situations. Chemical stabilization techniques include lime and cement columns, grouting, electroosmosis, and thermal (heating, freezing) techniques. Physical stabilization and densification techniques such as blasting, dynamic compaction, vibro-compaction and vibro-replacement, jet grouting, and stone columns have been utilized occasionally and quite successfully at some highway sites. Figure 6-7 shows a schematic diagram of a stone column installation. Details on design and installation of most chemical and physical stabilization techniques can be found in work by Welsh (1987) and Holtz (1989).

Reinforcement

Reinforcement involves the inclusion of some type of reinforcing elements at the interface between the embankment and the ground to increase the stability of the embankment. The most common types of embankment reinforcement are geotextiles and geogrids, although bamboo and brush fascines or mats, corduroy, short sheet piles, tie rods, and

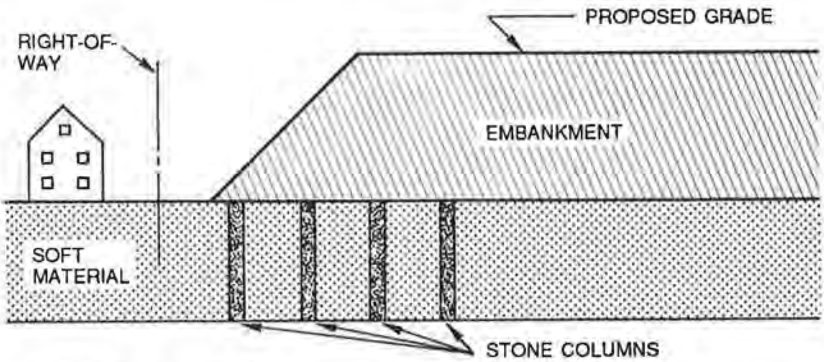


FIGURE 6-7 Stone columns used to stabilize highway embankment (*courtesy New York State Department of Transportation*).

the like have also been used. Common systems are shown in Figure 6-8. See *Geotextile Engineering Manual* (Christopher and Holtz 1985) and NCHRP Synthesis of Highway Practice 147 (Holtz 1989) for a discussion of the use, design, and construction of geotextiles to reinforce embankments on soft foundations.

Construction and Performance Monitoring

To ensure satisfactory construction and performance of the completed embankment, careful, competent inspection during construction is essential, especially for embankments in which some type of soil improvement and foundation treatment has been carried out. Visual observations and physical testing are obviously important components of construction inspection; perhaps not so obvious is that geotechnical instrumentation for taking measurements during construction is also an important aspect of construction monitoring. With a number of foundation treatments such as consolidation with vertical drainage, reinforcement, and chemical alteration, it may be desirable for foundation instrumentation and monitoring to continue for many years after construction is complete, especially if the particular treatment is considered experimental or if the stability of the site is marginal. Embankment instrumentation is discussed in Chapter 10 of this guide.

Inspection During Construction

The importance of well-trained, competent, and conscientious field and inspection personnel cannot be overemphasized. This is the only way to ensure that the essential features of the design are actually carried out in

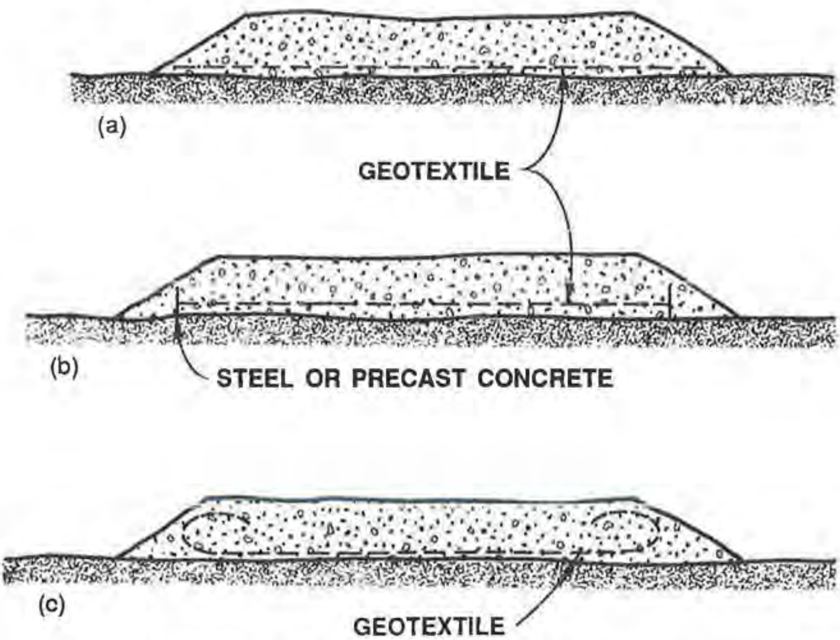


FIGURE 6-8 Concepts for using geotextiles to reinforce embankments on soft foundations (Christopher and Holtz 1985).

construction. With most, if not all, foundation improvement techniques, the success of the entire project is directly dependent on the success of the treatment, and competent inspection is the key element of the project.

To ensure that construction procedures for the treatment method are carried out properly, the designer should inform project engineers and field inspectors, by means of the project soils report and personal meetings prior to construction, about the important design concepts and key construction details of the treatment method. The on-site project engineer must be knowledgeable about the design assumptions to be able to make correct decisions about problems that will inevitably arise during construction. Uninformed construction decisions often result in cost overruns, contractor claims, or even failures.

REFERENCES

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
FHWA	Federal Highway Administration

AASHTO. 1988. *Manual on Subsurface Investigations.* Washington, D. C., 391 pp.

Cheney, R. S., and R. G. Chassie. 1984. *Soils and Foundation Workshop Manual.* FHWA, U. S. Department of Transportation, 338 pp.

Christopher, B. R., and R. D. Holtz. 1985. *Geotextile Engineering Manual.* Report FHWA-TS-86/203. FHWA, U. S. Department of Transportation, 1024 pp.

Holtz, R. D. 1987. Preloading with Prefabricated Vertical Strip Drains. *Geotextiles and Geomembranes,* Vol. 6, Nos. 1–3, pp 109–131.

Holtz, R. D. 1989. *NCHRP Synthesis of Highway Practice 147: Treatment of Problem Foundations for Highway Embankments.* TRB, National Research Council, Washington, D. C., 72 pp.

MacFarlane, I. C., ed. 1969. *Muskeg Engineering Handbook.* Muskeg Subcommittee of the NRC, University of Toronto Press.

Moore, L. H. 1966. Summary of Treatments for Highway Embankments on Soft Foundations. In *Highway Research Record 133.* HRB, National Research Council, Washington, D.C., pp. 45–57.

Rixner, J. J., S. R. Kraemer, and A. D. Smith. 1986. *Prefabricated Vertical Drains, Volume 1: Engineering Guidelines.* Report FHWA-RD-86/168. FHWA, U. S. Department of Transportation, 117 pp.

Sinacori, M. N., W. P. Hofmann, and A. H. Emery. 1952. Treatment of Soft Foundations for Highway Embankments. *Proc., Highway Research Board, 31st Annual Meeting.* National Research Council, Washington, D. C., pp. 601–621.

TRB. 1986. *Transportation Research Circular 309: Shared Experience in Geotechnical Engineering: Wick Drains.* National Research Council, Washington, D. C., 15 pp.

Terzaghi, K., and R. B. Peck. 1967. *Soil Mechanics in Engineering Practice,* 2nd ed. Wiley, New York, N. Y., 729 pp.

U. S. Navy. 1982. Soil Mechanics. *Design Manual 7.1,* and Foundations and Earth Structures. *Design Manual 7.2.* Naval Facilities Engineering Command, Alexandria, Va.

Welsh, J. P., ed. 1987. Soil Improvement—A Ten Year Update. *Proc., symposium sponsored by Committee on Placement and Improvement of Soils,* Atlantic City, ASCE, Geotechnical Engineering Division, Geotechnical Special Publication No. 12, 331 pp.

Winterkorn, H. F., and H.-Y. Fang, eds. 1975. *Foundation Engineering Handbook.* Van Nostrand Reinhold, New York, N. Y., 751 pp.