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Special Soil Deposits and Embankment Materials

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A number of soil deposits, both natural and man-made, can pose difficult problems for embankment foundations. These materials may be difficult, if not impossible, to sample and test by ordinary means, and thus their engineering behavior is not well documented or well understood. Consequently, normal practice, design rules, and experience may not lead to satisfactory embankment performance. A number of these special deposits are good candidates for some type of soil improvement and foundation stabilization, as discussed in Chapter 6, so that highway embankments can be constructed on them safely and with tolerable settlements. When used as fill directly in the embankment, these materials may cause unusual problems for the contractor and therefore for the field engineers and inspectors. Such materials may be stabilized and improved in special ways, some of which are mentioned in this chapter. Generally, such deposits and materials are handled by special provisions in the project specifications.

Deposits and materials discussed in this chapter include landfills, dumps, wastes from industrial and mining operations, lightweight fill materials, shales, swelling clays, and collapsible soils.

WASTE MATERIALS

Sanitary Landfills and Dumps

Roads in urban areas frequently must be located on sanitary landfills, garbage dumps, and similar areas. Construction is certainly possible on sanitary landfills, as shown by Moore and McGrath (1970) and Chang and Hannon (1976), but the results are often less than satisfactory unless some special foundation treatment is carried out. As noted by Holtz (1989), the types of problems encountered at such sites depend on the nature of the landfill materials and their age, both of which may be highly variable. Embankments on some well-operated landfills will normally consolidate rapidly, and thus only a simple surcharge is required to adequately densify them. In other instances, embankments on loosely dumped municipal garbage and building wastes will experience very large total and differential settlements, and this may mean a poor riding surface and high maintenance. Landfills that are 15 to 30 yr old may have already decomposed sufficiently to be good candidates for foundation treatment, although they may contain wastes that cause them to be considered hazardous by current Environmental Protection Agency (EPA) standards.

Feasible methods of foundation treatment (see Chapter 6) include the following:

- Proof rolling with very heavy rollers,
- Surcharge,
- Excavation and replacement as a compacted fill,
- Embankment piles,
- Grouting,
- Vibrocompaction, and
- Dynamic compaction.

Many waste dumps are not controlled landfills as described above, but are sites such as swamps, tidal flats, river and stream banks, lakes, and so on, where garbage, used appliances, wrecked cars, used tires, and the like have been often illegally discarded. In addition to the nature of the waste materials, the type and condition of the natural soils in the area must be considered in evaluating the site for possible foundation treatment.

Landfill sites pose other problems during construction. Decomposition of municipal wastes generates methane and carbon dioxide, and the introduction of fresh air into a dump site could cause a fire by spontaneous combustion or even from smoldering material buried in the landfill. Difficulties have been experienced with noxious gases, and in such cases it has been necessary for the field personnel to use breathing apparatus, apply deodorants to the site, and exercise special rodent and pest control measures after the area was opened.

Suspected toxic or hazardous waste dumps pose especially serious problems if they must be crossed by the highway. Special precautions must be taken to protect field crews, and it is prudent in these cases to call for specialized help.

Inorganic Industrial Wastes and Dredged Materials

Other wastes that are sometimes of concern to highway engineers include industrial by-products and wastes such as slags, bottom and fly ashes, and inorganic sludges. Dredged materials are sediments dredged from the bottoms of river channels, lakes, and harbors and deposited on land in diked containment areas. These waste materials are usually encountered in very localized areas, often near their source, although dredged materials and sludges may be transported some distance as slurries.

Loose deposits of predominantly granular materials such as slags and bottom ashes can be treated by methods appropriate for such materials (dynamic compaction, blasting, vibroreplacement). Provided proper environmental constraints are followed, they should make excellent embankment fills. Fly ashes are rarely foundation problems, and since they are mildly pozzolanic, they should be more than acceptable fill materials provided they are properly handled during transport, water addition and mixture, and compaction.

Sludge deposits and dredged materials, which may be silty or clayey or even somewhat organic, usually are a problem because of their high water content and compressibility. Holtz (1989) suggests acceptable foundation stabilization methods for these materials. Rarely do they make good fill materials.

Strip Mined Areas, Mine Wastes, Tailings, and Slurry Ponds

Both surface and underground mining operations usually leave rather unusual deposits and conditions that may cause locally difficult problems for embankment foundations. In addition, mineral processing operations also produce wastes in the form of tailings and slurries (slimes) that, if encountered, may be difficult to stabilize for construction.

Strip and underground mining operations often leave large areas of loosely dumped spoil materials. For embankment foundations, these deposits may be suitably treated (Holtz 1989), and in some cases may make excellent embankment fill.

Tailings from some mineral processing operations are another matter. They can be extremely difficult to stabilize for foundations, depending on their grain size and water content. Those factors, plus potentially hazardous conditions, for example, the presence of radioactivity, heavy metals, cyanide, or organics, make the use of tailings for highway fills very problematic. If such materials are suspected on your job, be sure that they meet all environmental requirements prior to approving their use as embankment fill.

LIGHTWEIGHT FILL MATERIALS

Both the stability and settlement of embankments on soft foundations can be improved by use of lightweight embankment fill (Moore 1966; Holtz 1989). Lightweight materials that have been used successfully in highway embankments include bark, sawdust, dried peat, fly ash, slag, cinders, cellular concrete, expanded clay or shale, expanded polystyrene, and oyster and clam shells. The advantages and disadvantages of the use of these materials are discussed by Holtz (1989).

Because the crushing strength of some lightweight materials is relatively low, care must be taken during construction to avoid damaging them, especially if conventional compaction equipment is used. Sometimes encapsulation is required for environmental reasons, and both synthetic liners (geomembranes) or compacted clay have been successfully used. In either case, great care must be taken during placement of the liner to avoid punctures, tears, and leaks. Strict adherence to the placement specifications is essential in these projects.

CONSTRUCTION OF EMBANKMENTS OF SHALE

The materials given the generic classification of "shale" are geologically widespread, and are frequently encountered in excavation and borrow situations. Two major problems have occurred when these materials have been used in highway embankments. Where the shales contain swelling clay minerals, the fills display the characteristic volume changes associated with swelling clays (see section on Compaction Problems with Swelling Clays). A somewhat more subtle problem situation occurs with the use of shales that are physically nondurable but are strong and rocklike when freshly excavated. Such materials have often been placed as rock fills, only to experience breakdown in service, producing excessive settlements and even slope failures.

This section concentrates on the technology required when building fills of hard but nondurable shales. These materials are commonly encountered throughout the midwestern United States, and thousands of examples of unsatisfactory performance have occurred where they were improperly placed.

Early classification of these materials is recommended, and the Franklin (1981) approach is appropriate. The primary test in this approach is the slake durability test, which combines two wet/dry cycles, with a rotational impact that dislodges slaked portions from the shale aggregates. The test is standardized as ASTM D 4644, Standard Test Method for Slake Durability of Shales and Similar Weak Rocks.

Once the second cycle slake durability index, $I_d\,(2)$, is defined, it serves as a general guide for relative durability and also determines the second test required to accomplish the Franklin classification. If the $I_d\,(2)$ is equal to or less than 80 percent, then a soil test such as the Atterberg limits and the plasticity index can be used to classify the material. On the other hand, if the $I_d\,(2)$ is greater than 80 percent, the point load strength index, adjusted for an aggregate dimension of 50.0 mm, must be used to complete the classification. All these procedures are briefly described in Oakland and Lovell (1983), and in greater detail in Oakland and Lovell (1982).

If the shale is nondurable and yet strong and hard, it is advisable to conduct a compaction-degradation test on it (Hale et al. 1981). A nondurable material must be intensely degraded during excavation, placement, and compaction, and it must be finally densified to a specification appropriate to a similar soil. This is difficult to accomplish with some shales, but the compaction-degradation test allows the problem to be anticipated.

The testing procedure, also described in Oakland and Lovell (1982), produces a numerical value, termed the index of crushing, which is the percentage reduction in mean aggregate size, produced in the laboratory compaction process. If this number is relatively high, for example, greater than about 40, the shale will be easily degraded in the field. If it has a lesser value, the shale will strongly resist efforts to break it down, and special wetting and heavy rolling procedures may be required. The procedures and compaction specifications for compacted shales are best developed in a full-scale field test pad, and the results of such tests should be made available to the project engineer. Special wetting and compaction procedures, if required, will be detailed in the special provisions of the project specifications.

Strom et al. (1978) and Strom (1980) have written good references on the design and construction of shale embankments.

COMPACTION PROBLEMS WITH SWELLING CLAYS

Compaction problems with swelling clays require special attention. Swelling soils, which are frequently clays but are sometimes shales, marls, or other soils, cause an estimated $10 billion in damage in the United States every year (Krohn and Slosson 1980). Half of this damage occurs to the nation's highways, with most of the remainder occurring to other transportation facilities such as airport runways, railroads, canals, pipelines, sidewalks, and so forth. Swelling materials occur in all but six states. The problem of swelling soils has been studied with considerable intensity through the years. One of the major efforts was a $700,000 research project funded by the Federal Highway Administration and conducted by the U. S. Army Corps of Engineers, Waterways Experiment Station, (Snethen et al. 1975; Snethen 1979 and 1980). Other major research has been done for the U. S. Air Force (McKeen 1980), and a variety of state agencies (for example, Watt and Steinberg 1972; Steinberg 1985). Many of these studies have been published by TRB (1981; 1985).

Once the contractor is aware of the potential of a swelling soils problem, standard Atterberg limits laboratory tests should confirm whether indeed there is a problem. From there on, the best advice is to avoid overcompacting the material. Density testing is a significant help in this regard. Keeping the material at a moisture level dictated by the density curves will assist in reducing the likelihood that the swelling material will turn the finished project into a roller coaster track in a few years. Properly compacting materials identified as having swelling potential and avoiding overcompaction are initial steps only. When embankments are constructed with swelling materials, the results tend to be satisfactory over an extended period of time, certainly much more so than when dealing with swelling clays in an excavation area.

Because the problem of expansive soils is an international one, it is reassuring to know that several solutions have been tried and found to be successful. Lime treatment has been used successfully both in the United States and abroad (TRB 1987). The important thing to remember is that enough lime should be used and that it should be placed to a depth that will control the potential movement. (Potential vertical rise tests will give an indication of what these depths might be.) Electro-osmotic chemical stabilization and pressure injection of chemicals, primarily lime, have been used, but with mixed results.

The key to the successful mitigation of the effects of swelling soils seems to be in minimizing moisture variation underneath the structure, be it a pavement, building, runway, track, or whatever, to prevent the destructive movements from taking place. Moisture barriers have been tried in several locations. Examples include pressure-injected lime barriers, deep vertical fabric barriers, and horizontal geomembranes. These tests have been reported by TRB (1981; 1985) as well as state transportation agencies (Steinberg 1985). Ponding has also been used in several instances to solve earthwork construction difficulties with swelling materials. Watt and Steinberg (1972) drilled holes 20 ft deep, backfilled them with a pervious material, and then ponded water in them for 30 days. This procedure produced sections that have not had to be replaced because of subgrade problems.

Studies are continuing on swelling soils, and to minimize the damage these soils cause transportation structures and facilities, the engineer should be aware of the results of this research.

COLLAPSING AND SUBSIDING SOILS

Collapsing soils undergo a very large decrease in volume if their water content increases significantly, even without an increase in surface load. Examples include loessial soils, weakly cemented sands and silts, and certain residual soils. All these soils have a loose, open, "honeycomb" structure, in which the larger bulky grains are held together by capillary films, montmorillonite or other clay minerals, or soluble salts such as halite, gypsum, or carbonates. Loess is, of course, wind-deposited; other collapsible soils are found on flood plains and in alluvial fans as the remains of slope wash and mud flows, colluvial slopes, and some residual soil deposits. Many, but not all, collapsible soil deposits are associated with dry or semi-arid climates, but some dredged material deposits and hydraulic fills can also be collapsible.

Treatment methods for collapsible soils depend on the depth of treatment required. For modest depths, compaction with rollers, wetting or inundation, and overexcavation and recompaction, sometimes with lime or cement stabilization, are used (Bara 1978). Dynamic compaction (Lukas 1986) may also be feasible. For thicker deposits, ponding or flooding are ordinarily very effective, as is dynamic compaction. However, explosives, displacement piles, and vibroreplacement-vibrocompaction methods could possibly be used as well. Design information for the deeper stabilization methods is given by Clemence and Finbarr (1981) and summarized by Holtz (1989). Any of these procedures required would be detailed in the special provisions of the project specifications.

LOOSE SATURATED SANDS IN EARTHQUAKE COUNTRY; FLOW SLIDES

It is possible for deposits of loose, saturated granular materials to lose all strength when subjected to shock or vibrations from, for example, blasting, pile driving, or earthquakes. The phenomenon is called liquefaction, and it results because there is a tendency for loose sands to decrease in volume when strained or shocked. This tendency causes a positive increase in pore water pressure which results in a decrease in effective stress within the soil mass. Once the pore pressure becomes equal to the total stress, the effective stress becomes zero, and the soil mass loses all its strength (Holtz and Kovacs 1981). Because this loss in shear strength is sudden, the effect on highway embankments and other structures supported by such deposits is disastrous.

Flow slides are a type of liquefaction that occurs almost spontaneously in loose deposits of fine sands often found on the banks of large rivers. When these deposits are strained, say by erosion at the river's edge, excess pore pressures can develop which can lead to liquefaction and collapse of the deposit.

Because of the potential for catastrophic collapse of the foundation of an embankment on liquefiable sands, it is important that these deposits be identified and treated before construction. Virtually all the methods described by Holtz (1989) for granular materials are appropriate for densifying or stabilizing such deposits. Particularly attractive are dynamic compaction, blasting, vibrocompaction and replacement methods, relief wells and drains, and excavation and replacement. These procedures are quite specialized and would be given in the special provisions of the project specifications.

REFERENCES

ABBREVIATIONS

ASCE	American Society of Civil Engineers
FHWA	Federal Highway Administration

Bara, J. P. 1978. Collapsible Soils and their Stabilization. In *Soil Improvement, History, Capabilities and Outlook.* Report by Committee on Placement and Improvement of Soils, Geotechnical Engineering Division, ASCE, pp. 141–152.

Chang, J. C., and J. B. Hannon. 1976. Settlement Performance of Two Test Highway Embankments on Sanitary Landfill. *Proc., International Symposium on New Horizons in Construction Materials,* Lehigh University, Vol. I, pp. 139–157.

Clemence, S. P. and A. D. Finbarr. 1981. Design Considerations for Collapsible Soils. *Journal of the Geotechnical Engineering Division,* Vol. 107, No. GT3, ASCE, pp. 305–317.

Franklin, J. A. 1981. A Shale Rating System and Tentative Applications to Shale Performance. In *Transportation Research Record 790.* TRB, National Research Council, Washington, D. C., pp. 2–12.

Hale, B. C., C. W. Lovell, and L. E. Wood. 1981. Development of a Laboratory Compaction-Degradation Test for Shales. In *Transportation Research Record 790.* TRB, National Research Council, Washington, D. C. pp. 45–52.

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.

Holtz, R. D., and W. D. Kovacs. 1981. *An Introduction to Geotechnical Engineering.* Prentice-Hall, Inc., 733 pp.

Krohn, J. P., and J. E. Slosson. 1980. Assessment of Expansive Soils. *Proc., 4th International Conference on Expansive Soils,* Denver, Colo., Vol. 1, ASCE.

Lukas, R. G. 1986. *Dynamic Compaction for Highway Construction. Volume I: Design and Construction Guidelines.* Report FHWA/RD-86/133. FHWA, U. S. Department of Transportation, 241 pp.

McKeen, R. G. 1980. Field Studies of Airport Pavements on Expansive Clay. *Proc., 4th International Conference on Expansive Soils,* Denver, Colo., Vol. 1, ASCE, pp. 242–261.

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.

Moore, L. H., and M. E. McGrath. 1970. Highway Construction on Refuse Fills. *Highway Focus,* Vol. 2, No. 5. FHWA, U. S. Department of Transportation, pp. 11–28.

Oakland, M. W., and C. W. Lovell. 1982. *Classification and Other Standard Tests for Shale Embankments.* FHWA/IN/JHRP Report 82/4, School of Civil Engineering, Purdue University, W. Lafayette, Ind., 171 pp.

Oakland, M. W., and C. W. Lovell. 1983. Standard Tests for Compacted Shales. In *Transportation Research Record 873.* TRB, National Research Council, Washington, D. C., pp. 15–22.

Snethen, D. R. 1979. *Technical Guidelines for Expansive Soils in Highway Subgrades.* Report FHWA-RD-79-51. FHWA, U. S. Department of Transportation, 168 pp.

Snethen, D. R. 1980. *Expansive Soils in Highway Subgrades: Summary.* Report FHWA-TS-80-236. FHWA, U. S. Department of Transportation, 30 pp.

Snethen, D. R. et al. 1975. *A Review of Engineering Experience with Expansive Soils in Highway Subgrades.* Report FHWA-RD-75-48. FHWA, U. S. Department of Transportation.

Steinberg, M. L. 1985. *Monitoring the Use of Impervious Fabrics, Geomembranes, in the Control of Expansive Soils.* Report FHWA-TX-86-72 and 187-12. Texas State Department of Highways and Public Transportation, Austin.

Strom, W. E. Jr., G. H. Bragg, Jr., and T. W. Ziegler. 1978. *Design and Construction of Compacted Shale Embankments: Vol. 5, Technical Guidelines.* Report FHWA-RD-78-141. FHWA, U. S. Department of Transportation, 216 pp.

Strom, W. E., Jr. 1980. *Design and Construction of Shale Embankments: Summary.* Report FHWA-TS-80-219. FHWA, U. S. Department of Transportation, 22 pp.

TRB. 1981. *Transportation Research Record 790: Shales and Swelling Soils.* National Research Council, Washington, D. C.

TRB. 1985. *Transportation Research Record 1032: Evaluation and Control of Expansive Soils.* National Research Council, Washington, D. C.

TRB. 1987. *State of the Art Report 5: Lime Stabilization.* National Research Council, Washington, D. C., 59 pp.

Watt, W. G., and M. L. Steinberg. 1972. *Measurements of a Swelling Clay in a Ponded Cut.* Texas Highway Department Research Report No. 118-b, Cooperative Highway Research Program, Center for Highway Research, University of Texas, Austin.