CHAPTER 7

MINIMIZATION OF FOUNDATION MOVEMENT

7-1. Preparation for construction

The foundation should always be provided with adequate drainage, and the soil properly prepared to minimize changes in soil moisture and differential movement.

a. Removal of vegetation. Existing trees and other heavy vegetation should be removed. New plantings of like items installed during postconstruction landscaping should not be located within a distance away from the structure ranging from 1 to 1.5 times the height of the mature tree.

b. Leveling of site. Natural soil fills compacted at the natural water content and the natural density of the in situ adjacent soil minimize differential movement between cut and fill areas of sloping ground, trenches, or holes caused by removal of vegetation. The volume of cut portions should be kept to a minimum. Cut areas reduce the overburden pressure on underlying swelling soil and lead to time-dependent heave.

c. Excavation.

(1) Construction in new excavations (within a few years of excavating) without replacement of a surcharge pressure equal to the original soil overburden pressure should be avoided where possible because the reduction in effective stress leads to an instantaneous elastic rebound plus a time-dependent heave. The reduction in overburden pressure results in a reduction of the pore water pressure in soil beneath the excavation. These pore pressures tend to increase with time toward the original or equilibrium pore pressure profile consistent with that of the surrounding soil and can cause heave.

(2) Ground surfaces of new excavations, such as for basements and thick mat foundations, should be immediately coated with sprayed asphalt or other sealing compounds to prevent drying of or the seepage of ponded water into the foundation soil during construction (fig. 7-1). Rapid-cure RC 70 or medium-cure MC 30 cutback asphalts are often used as sealing compounds, which penetrate into the soil following compaction of the surface soil and cure relatively quickly.

7-2. Drainage techniques

Drainage is provided by surface grading and subsurface drains.

a. Grading. The most commonly used technique is grading of a positive slope away from the structure. The slope should be adequate to promote rapid runoff and to avoid collecting, near the structure, ponded water, which could migrate down the foundation/soil interface. These slopes should be, greater than 1 percent and preferably 5 percent within 10 feet of the foundation,

(1) Depressions or water catch basin areas should be filled with compacted soil (para 7-3a) to have a positive slope from the structure, or drains should be provided to promote runoff from the water catch basin areas. Six to twelve inches of compacted, impervious, nonswelling soil placed on the site prior to construction of the foundation can ensure the necessary grade and contribute additional uniform surcharge pressure to reduce uneven swelling of underlying expansive soil.

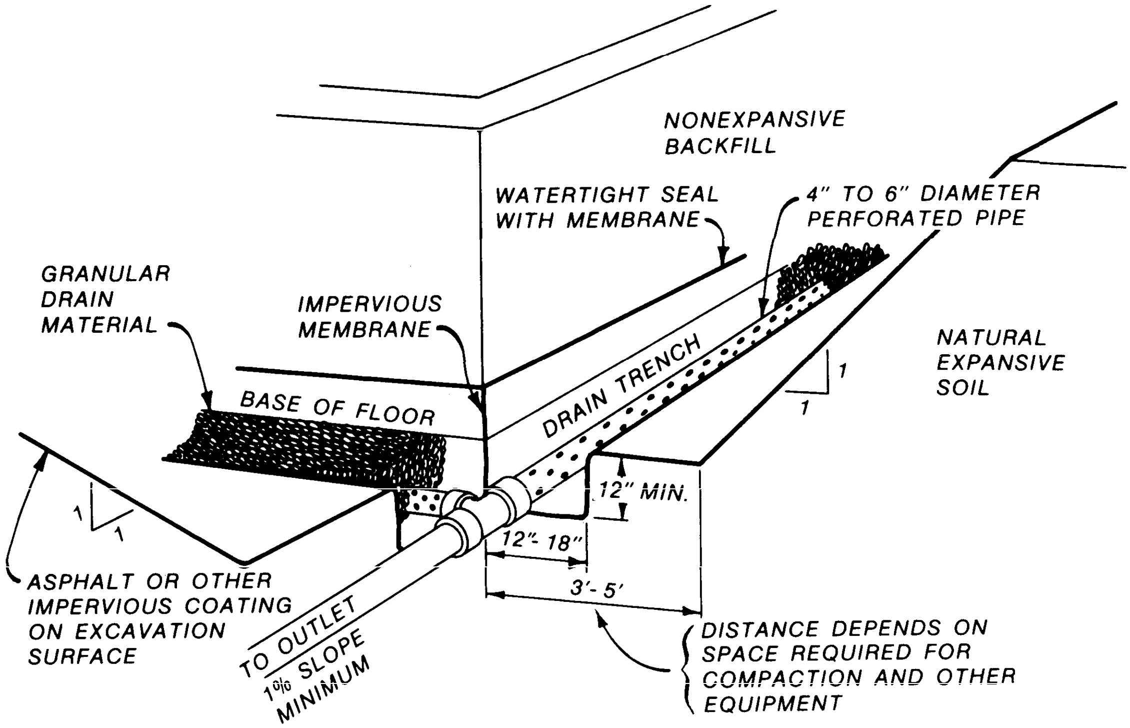
(2) Grading and drainage should be provided for structures constructed on slopes, particularly for slopes greater than 9 percent, to rapidly drain off water from the cut areas and to avoid pending of water in cuts or on the uphill side of the structure. This drainage will also minimize seepage through backfills into adjacent basement walls.

b. Subsurface drains. Subsurface drains (fig. 7-1) may be used to control a rising water table, groundwater and underground streams, and surface water penetrating through pervious or fissured and highly permeable soil. Drains can help control the water table before it rises but may not be successful in lowering the water table in expansive soil. Furthermore, since drains cannot stop the migration of moisture through expansive soil beneath foundations, they will not prevent all of the long-term swelling.

(1) *Location of subsurface drains,* These drains are usually 4- to 6-inch-diameter perforated pipes placed adjacent to and slightly below the baseline of the external wall to catch free water (fig. 7-1).

(a) An impervious membrane should be placed beneath the drain in the trench to prevent migration of surface moisture into deeper soil. The membrane adjacent to the foundation wall should be cemented to the wall with a compatible joint sealant to prevent seepage through the joint between the membrane and the foundation.

(b) If a 6- to 12-inch layer of granular material



U. S. Army Corps of Engineers

Figure 7-1. Drainage trench around outside of structure.

was provided beneath a slab-on-grade, the granular material in the drain trench should be continuous with the granular material beneath the floor slab. The perforated pipe should be placed at least 12 inches deeper than the bottom of the granular layer. An impervious membrane should also be placed on the bottom and sides of the drain trench but should not inhibit flow of moisture into the drain from beneath the floor slab. Granular fills of high permeability should be avoided where possible.

(c) Deep subsurface drains constructed to control arising water table should be located at least 5 feet below a slab-on-grade. An impervious membrane should not be placed in the drain trench. These drains are only partially effective in controlling soil heave above the drain trench, and they are relatively expensive. A more economical solution may be to place a temporary (or easily removable slab-on-grade) with a permanent slab after the groundwater table has reached equilibrium.

(2) *Outlets.* Drains should be provided with outlets or sumps to collect water and pumps to expel water if gravity drainage away from the foundation is not feasible. Sumps should be located well away from the structure. Drainage should be adequate to prevent any water from remaining in the drain (i.e., a slope of at least 1/8 inch per foot of drain or 1 percent should be provided).

(3) *Drain trench material.* The intrusion of fines in drains maybe minimized by setting the pipe in filter fabric and pea gravel/sand.

7-3. Stabilization techniques

Two effective and most commonly used soil stabilization techniques are controlled backfilling and continuous maintenance involving drainage control and limited watering of surface soil adjacent to the structure during droughts. Other techniques, such as moisture barriers and lime treatment, are not widely used in minimizing differential heave of single and multistory buildings. Presetting or pending for periods of a few months to a year prior to construction is often effective but normally is not used because of time requirements. Prewetting should not be used on fissured clay shales because swelling from water seeping into fissures may not appear until a much later date and delayed problems may result.

a. *Controlled backfills.* Removal of about 4 to 8 feet of surface swelling soil and replacement with nonexpansive, low permeable backfill will reduce heave at the ground surface. Backfills adjacent to foundation walls should also be nonswelling, low permeable material. Nonswelling material minimizes the forces exerted on walls, while low permeable backfill minimizes infiltration of surface water through the backfill into the foundation soil. If only pervious, nonexpansive (granular) backfill is available, a subsurface drain at the bottom of the backfill is necessary to carry off infiltrated water (fig. 7-1) and to minimize seepage of water into deeper desiccated foundation expansive soils.

(1) *Backfill of natural soil.* Backfill using natural soil and compaction control has been satisfactory in some cases if nonswelling backfill is not available. However, this use of backfill should be a last resort,

(a) In general, the natural soil should be compacted to 90 percent of standard maximum density and should be wet of optimum water content. Foundation loads on fills should be consistent with the allowable bearing capacity of the fill. Overcompaction should be avoided to prevent aggravating potentially swelling soil problems such as differential heave of the fill. Compaction control of naturally swelling soil is usually difficult to accomplish in practice. Some soils become more susceptible to expansion following remolding, and addition of water to achieve water contents necessary to control further swell may cause the soil to be too wet to work in the field.

(b) As an alternative, backfills of lime-treated natural soil compacted to 95 percent standard maximum density at optimum water content may be satisfactory if the soil is sufficiently reactive to the lime *(d* below), Lime treatment may also increase soil strength and trafficability on the construction site.

(2) *Backfill adjacent to walls.* A IV on lH slope cut into the natural soil should dissipate lateral swell pressures against basement or retaining walls exerted by the natural swelling material. The nonswelling backfill should be a weak material (sand fill with friction angle of 30 degrees or lessor cohesive fill with cohesion less than about 0.5 tons per square foot) to allow the fill to move upward when the expansive natural soil swells laterally. Restraining loads should not be placed on the surface of the fill. A friction reducing medium may be applied on the wall to minimize friction between the wall and the backfill, TM 5-818-4 discusses details on optimum slopes of the excavation and other design criteria.

b. Maintenance. Maintenance programs are directed toward promoting uniform soil moisture beneath the foundation. A good program consists of the following:

(1) Maintenance of a positive slope of about 5 percent around the structure for drainage and elimination of water catch areas.

(2) Maintenance of original drainage channels and installation of new channels as necessary.

(3) Maintenance of gutters around the roof and diversion of runoff away from the structure.

(4) Avoidance of curbs or other water traps around flower beds.

(5) Elimination of heavy vegetation within 10 to 15 feet of the foundation or 1 to 1.5 times the height of mature trees.

(6) Uniform limited watering around the structure during droughts to replace lost moisture.

c. Moisture barriers. The purpose of moisture barriers is to promote uniform soil moisture beneath the foundation by minimizing the loss or gain of moisture through the membrane and thus reducing cyclic edge movement, Moisture may still increase beneath or within areas surrounded by the moisture barriers leading to a steady but uniform heave of the foundation or slab-on-grade.

(1) *Types of barriers.* These barriers consist of horizontal and vertical plastic and asphalt membranes and granular materials. Concrete is an ineffective moisture barrier. Longlasting membranes include chlorinated polyethylene sheets, preferably placed over a layer of catalytically blown or sprayed asphalt. All joints, seams, and punctures should be sealed by plastic cements or concrete/asphalt joint sealants. ASTM D 2521 (Part 15) describes use of asphalt in canal, ditch, and pond linings (app A).

(2) *Horizontal.*

(a) An impervious membrane on the ground surface in a crawl space where rainfall does not enter may help reduce shrinkage in clayey foundation soils with deep groundwater levels by minimizing evaporation from the soil. A vapor barrier should not be placed in ventilated crawl spaces if there is a shallow water table or if site drainage is poor because heave maybe aggravated in these cases. Figure 7-2 illustrates a useful application of horizontal membranes,

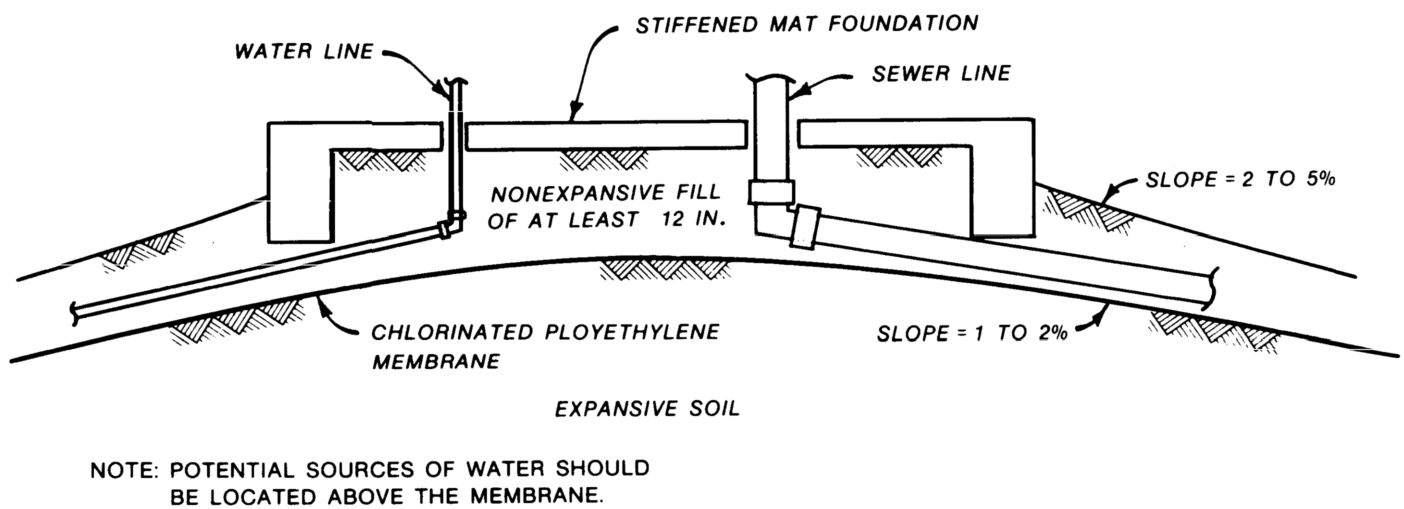
(b) Other applications include the use of horizontal moisture barriers around the perimeter of structures to reduce lateral variations in moisture changes and differential heave in the foundation soil. Plastic or other thin membranes around the perimeter should be protected from the environment by a 6- to 12-inch-thick layer of earth.

(c) A disadvantage of these barriers is that they are not necessarily reliable and may be detrimental in some cases. For example, most fabrics and plastic membranes tend to deteriorate with time. Undetected (and hence unrepaired) punctures that allow water to get in, but not to get out, commonly occur in handling on placement. Punctures may also occur during planting of vegetation. If the barrier is a concrete slab, the concrete may act as a wick and pull water out of the soil.

(3) *Vertical.*

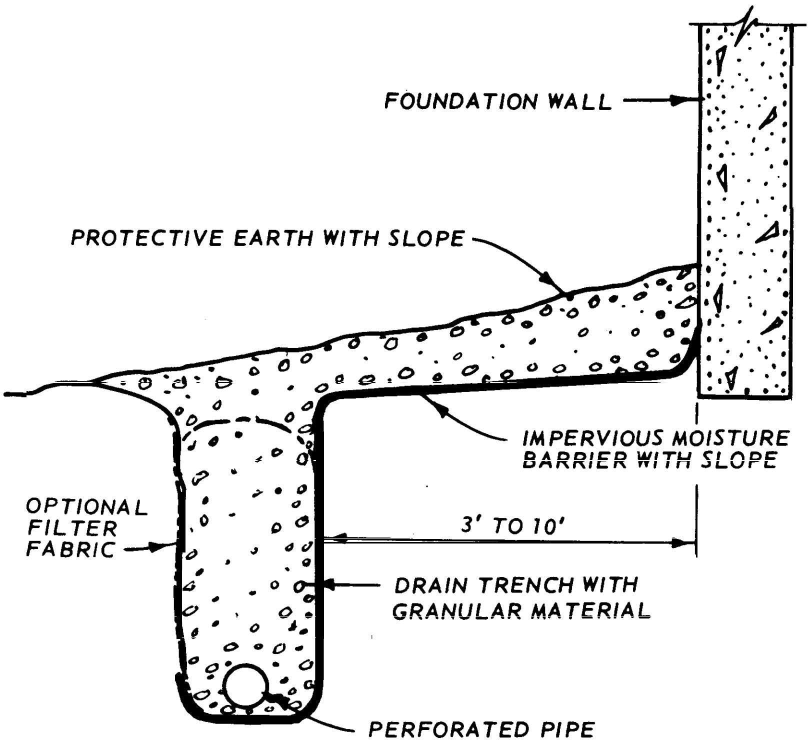
(a) Plumbing or utility trenches passing through the barrier may contribute to soil moisture beneath the foundation.

(b) The vertical barrier (fig. 7-3) should extend to the depth of the active zone and should be placed a minimum of 3 feet from the foundation to simplify construction and to avoid disturbance of the foundation soil. The barrier may not be practical in prevent-



U. S. Army Corps of Engineers

Figure 7-2. Application of a horizontal membrane.



U. S. Army Corps of Engineers

Figure 7-3. Vertical and horizontal moisture barriers.

ing migration of moisture beneath the bottom edge for active zones deeper than 8 to 10 feet. The granular barrier may also help reduce moisture changes during droughts by providing a reservoir of moisture. The placement of a filter fabric around the trench to keep fine particles from entering the perforated pipe will permit use of an open coarse aggregate instead of a graded granular filter. In some cases, the perforated pipe could be eliminated from the drain trench.

d. Lime treatment. This treatment is the most widely used and most effective technique of chemical alteration to minimize volume changes and to increase the shear strength of foundation expansive soils.

(1) *Applications.* Lime treatment is applied to the strengthening and minimization of volume change of soil in railroad beds, pavement subgrades, and slopes. When this treatment is applied to foundation soils of single and multistory structures, it is not always successful because the usefulness depends on the reactiveness of the soil to lime treatment and the thoroughness of dispersion of lime mixed into the soil.

(a) Lime treatment is effective in the minimization of volume changes of natural soil for backfill. However, this treatment increases the soil permeability and the soil strength. The soil permeability should be kept low to restrict seepage of surface water through the backfill. The backfill strength should be as low as possible compatible with economical design to minimize the transfer of lateral swell pressures from the natural in situ soil through the backfill to the basement and retaining walls.

(b) Lime treatment may be used to stabilize a 6- to 12-inch layer of natural expansive soil compacted on the surface of the construction site to provide a positive slope for runoff of water from the structure and a layer to reduce differential heave beneath the floor slab.

(c) Lime treatment may be applied to minimize downhill soil creep of slopes greater than 5 degrees (9 percent) by increasing the stiffness and strength of the soil mass through filling fractures in the surface soils. If lime slurry pressure injection (LPSI) can cause a lime slurry to penetrate the fissures in the soil mass to a sufficient depth (usually 8 to 10 feet), then the lime-filled seams will help control the soil water content, reduce volumetric changes, and increase the soil strength. However, LSPI will probably not be satisfactory in an expansive clay soil that does not contain an extensive network of fissures because the lime will not penetrate into the relatively impervious soil to any appreciable distance from the injection hole to form a continuous lime seam moisture barrier.

(d) LSPI may be useful for minimization of movement of fissured foundation expansive soils down to the depth of the active zone for heave or at least 10 ft. The lime slurry is pressure injected on 3- to 5-foot center to depths of 10 to 16 feet around the perimeter of the structure 3 to 5 feet from the structure.

(2) *Soil mixture preparation.* Lime should be thoroughly and intimately mixed into the soil to a sufficient depth to be effective. For stabilization of expansive clay soils for foundations of structures, mixing should be done down to depths of active zone for heave. In practice, mixing with lime is rarely done deeper than 1 to 2 feet. Therefore, lime treatment is normally not useful for foundations on expansive soil except in the above applications. Moreover, poor mixing may cause the soil to break up into clods from normal exposure to the seasonal wetting/drying cycles. The overall soil permeability is increased and provides paths for moisture flow that require rapid drainage from this soil. Lime treatment should be performed by experienced personnel.

(3) *Lime modification optimum content (LMO).* The LMO corresponds to the percent of lime that maximizes the reduction in the soil plasticity or the PI. The reduction in plasticity also effectively minimizes the volume change behavior from changes in water content and increases the soil shear strength.

(a) A decision to use lime should depend on the degree of soil stabilization caused by the lime. Lime treatment is recommended if a 50 percent reduction in the PI is obtained at the LMO content (table 7- 1). The PI should be determined for the natural soil, LMO, LMO+ 2, and LMO - 2 percent content.

(b) The increase in strength of the lime-treated soil should be similar for soil allowed to cure at least 2 or more days following mixing and prior to compaction to similar densities.

(c) The amount of lime needed to cause the optimum reduction in the PI usually varies from 2 to 8 percent of the dry soil weight.

e. Cement treatment. Cement may be added to the soil to minimize volume changes and to increase the shear strength of the foundation expansive soil if the degree of soil stabilization achieved by lime alone is not sufficient. The amount of cement required will probably range between 10 to 20 percent of the dry soil weight. A combination of lime-cement or lime-cement-fly ash may be the best overall additive, but the best combination can only be determined by a laboratory study. TM 5-822-4 presents details on soil stabilization with cement and cement-lime combinations.

Table 7-1. pH Test Procedure for the Lime Modification Optimum Content

Materials:

1. Lime to be used for soil stabilization.
2. Air-dried soil.

Apparatus:

1. pH meter (the pH meter must be equipped with an electrode having a pH range of 14).
2. 150-ml (or larger) plastic bottles with screw-top lids.
3. 50-ml plastic beakers.
4. CO_2—free distilled water.
5. Balance.
6. Oven.
7. Moisture cans.

Procedure:

1. Standardize the pH meter with a buffer solution having a pH of 12.45.
2. Weigh to the nearest 0.01 g representative samples of air-dried soil, passing the No. 40 sieve and equal to 20.0 g of oven-dried soil.
3. Pour the soil samples into 150-ml plastic bottles with screw-top lids.
4. Add varying percentages of lime, weighed to the nearest 0.01 g, to the soils. (Lime percentages of 0, 1, 2, 3, 4, 5 6, and 8, based on the dry soil weight, may be used.)
5. Thoroughly mix soil and dry lime.
6. Add 100 ml of CO_2—free distilled water to the soil-lime mixtures.
7. Shake the soil-lime and water for a minimum of 30 sec or until there is no evidence of dry material on the bottom of the bottle.
8. Shake the bottles for 30 sec every 10 min.
9. After 1 hr, transfer parts of the slurry to a plastic beaker and measure the pH.
10. Record the pH for each of the soil-lime mixtures. The lowest percent of lime giving a pH of 12.40 is the percent required to stabilize the soil. If the pH does not reach 12.40, the minimum lime content giving the highest pH is that required to stabilize the soil.