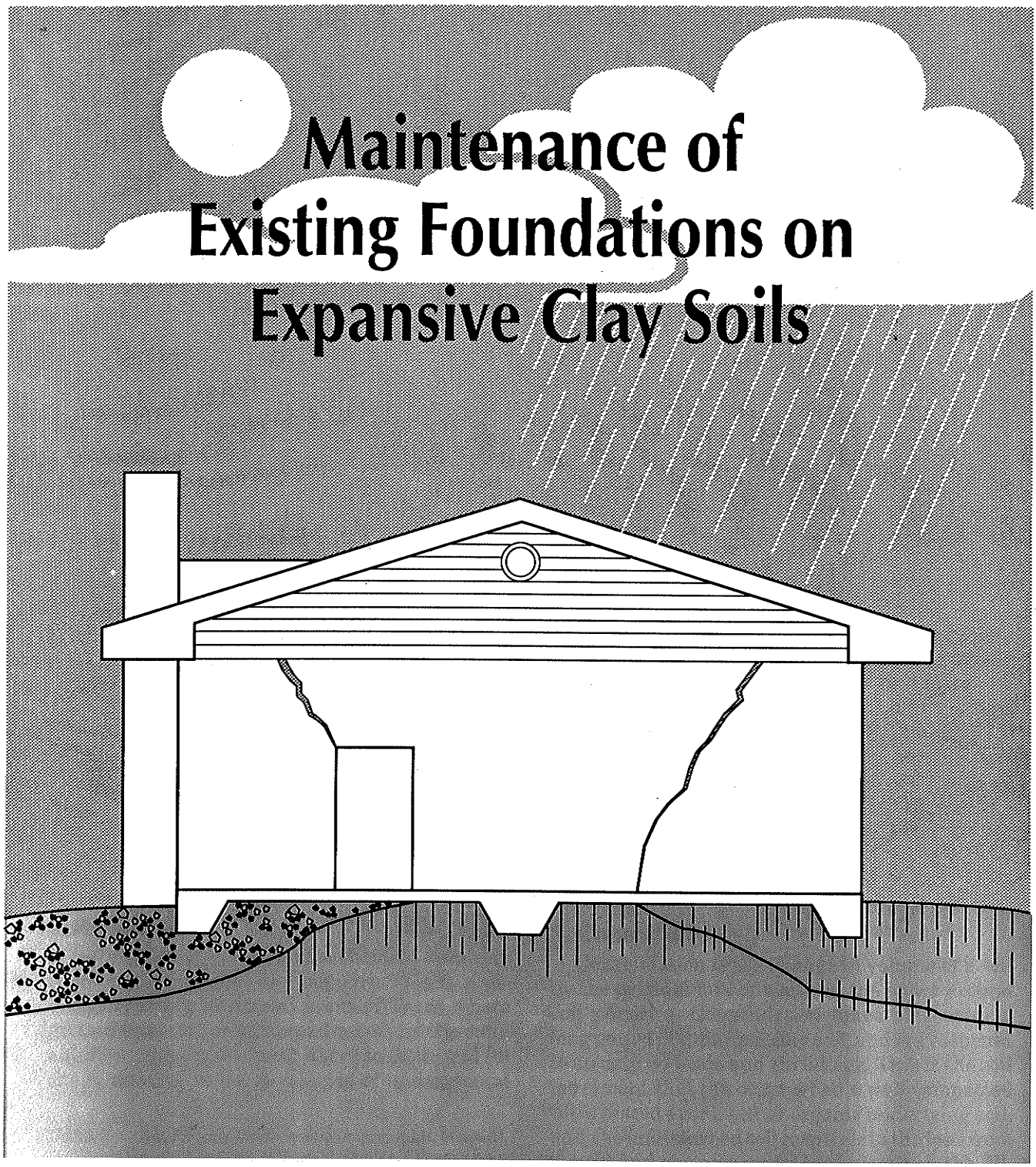
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Maintenance of Existing Foundations on Expansive Clay Soils



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Maintenance of Existing Foundations on Expansive Clay Soils

Judith B. Corley, J.H. Marsh III and Susan M. Quiring*

This is one of a series of Extension publications on home construction. The focus of this publication is on maintaining existing foundations and prevention of severe damage from swelling and shrinking of clay soils. Other publications in this series are on topics that relate to foundation cracking, foundation design and foundation movement.

Residential foundation problems have plagued Texans for years but problems associated with foundation movements have intensified since the introduction of the slab-on-grade foundation in the late 1940s. It is important to understand the factors contributing to foundation movements in order to maintain the existing structure so that future damage is minimized.

If we assume that a house foundation is adequate to transmit the design loads to the supporting soil, then any subsequent movement in the foundation must be attributable to movement within the soil. Distress cracks in brick veneer exteriors and gypsum board interior wall surfaces are usually the first indicators that foundation movement is occurring.

Soil Movement

Soil movement can be caused by numerous factors including subsidence, compaction, consolidation and moisture changes. While this publication is concerned with foundation movement caused by moisture changes, the four factors are described as follows:

1. Subsidence

Subsidence is the ground settlement resulting from loss of underground support. This is presently occurring in coastal areas of Texas where ground water is being pumped out of underground aquifers, causing the earth above to settle and fill the remaining voids. A collapse of underground support of any sort could cause subsidence if the soil cannot bridge the resulting voids. Foundation movement caused by this phenomenon cannot be corrected or controlled by home maintenance and can be designed only when large scale and costly geological surveys are carried out.

2. Soil Compaction

Soil that is disturbed will occupy a larger volume than undisturbed soil because of the air filling the area around each soil aggregate. Compaction is change in volume due to removal of some space. When a foundation is being prepared, the disturbed soil should be recompacted to a proper density and moisture content. Improperly compacted fill will settle with time due to moisture flow through the soil, vibrations and structural loading. If the settlement is uniform across the entire foundation, there will be very little noticeable effect.

Any non-uniform settlement of foundation soil must be bridged by the foundation structure; otherwise, it will flex or shear, and distress cracks often will appear. Differential forces occur on foundation segments introducing bending, shear, torsion, or all three. Any foundation movement is transmitted to the structure resting upon it and this is amplified by the height of the walls, usually causing distress to the masonry veneer and interior wall surfaces. Unfortunately, foundation movements on poorly compacted fill are generally non-uniform.

3. Consolidation

Consolidation is the change in volume of a soil by the gradual loss of water in the space around soil particles. Consolidation takes place over a long period of time for a clay soil, and is a response to structural loads and shrinkage. This is the soil movement that can occur when a well-compacted fill is placed over a soft or organic underlying soil, and the undisturbed soil responds to the load from the fill and any structural load placed on the fill.

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Settlements due to consolidation are most likely on soft clays which tend to have higher moisture content, and the amount and time rate of settlement can be predicted.

4. Moisture Changes in the Soil

Sandy type soils, unlike clay soils, will not undergo volume changes with changes of soil moisture if they are properly compacted. Most clay soils, however, will shrink or swell with a change in moisture. A clay soil will increase in volume both horizontally and vertically when its moisture content increases. The same soil will shrink in all directions when the moisture content decreases and the soil dries. Some clays exhibit little change while others undergo appreciable change. Most clays in Texas are of the moderate to high volume change types.

It would be ideal to have a foundation which rests upon soils that expand or contract uniformly under all areas. Typically, it is difficult for all sides and areas of a foundation to be at a constant moisture content because the foundation itself provides a shelter from weather conditions to the soil underneath it. The moisture change of the perimeter areas is more rapid due to its exposure to the climate elements including both rainfall and evaporation, i.e., both drying and wetting. Also, the slope of the site will effect moisture concentrations, as will trees, roof drainage and orientation to sun, wind and shade. Broken and leaking plumbing lines under a foundation, or leakage from swimming pools or sprinkler systems also can be disastrous because they add moisture to the soil unevenly.

A residential foundation should be able to accommodate movement from the soil it rests upon, including seasonal movement. Properly designed and constructed foundations can accommodate reasonable moisture changes due to seasonal variations. However, when severe dryness occurs, even the best of foundations can show signs of distress with accompanying drywall and masonry damage. Similarly, an unusually wet period will result in damage to structures if the underlying soils have been dry for prolonged periods. Most residential foundations need proper design in addition to the local or regulatory minimum standards for reinforcement and concrete thickness. Consideration should be given to the types of soil, preparation of the foundation site including compaction of fill, the effects of cuts, and ground slope and presence of trees. Site drainage should not be ignored, or the result will affect runoff moisture that is trapped, usually non-uniformly, around the edge of the foundation. All of these factors affect the movement of foundations because the pressure exerted by the swelling clay due to an increase in moisture content is higher than the loading pressure due to the structure.

Climate

Expansive clay soils are clays that shrink and swell with changes in soil moisture. In many areas of Texas, initial shrinkage occurs more often than swelling because the climate is generally dry. Under these conditions large tension cracks are easy to see in the yard during the summer months. The shaded areas of the Texas map in Figure 1 show areas with significant expansive clay soils. Other areas also are affected by the clays, but to a lesser extent. Note that a large portion of the most populated areas of Texas occurs within the area of highly expansive clay soils. Included within this clay band are cities such as Sherman, Paris, Denton, Dallas, Fort Worth, Waco, Austin, Temple, Hillsboro, Bryan-College Station, Houston, Beaumont and San Antonio.

Because the expansive clay soil changes in volume with changing soil moisture, climate is an important factor in the behavior of the soil. If the expansive clay soil is moist to a depth of 10 to 15 feet and is not allowed to dry out, the volume of the soil will not change. However, the soil will shrink and cracks will form if the wet soil mass dries from the surface because of evaporation or plant water use. Similarly, if the soil is initially dry, no swelling will occur if moisture is prevented from entering the soil. The difficulty is that it is almost impossible to prevent rainfall from entering the dry soil, flowing in the soil cracks and causing the clay soil to swell.

Pavements, including highways, roads and driveways, are also affected by the shrinkage and swelling of the clay soils. Because of this, the climate of the United States has been classified into nine moisture and temperature zones by the climatologist C.W. Thornthwaite in his 1948 paper in *Geographical Review*. Texas has a variety of climate types that affect the clay soil behavior. The six climate zones located in Texas are sketched on the map found on Figure 2, and each zone is described in terms of annual moisture balance and temperature fluctuations. Zone I-B, in which Texarkana is located, has relatively wet conditions, and occasional moderate freezing. The area located south of this is also relatively wet, but has less likelihood of freezing. Beaumont is located in this I-C climate zone. Climate zone II-B contains

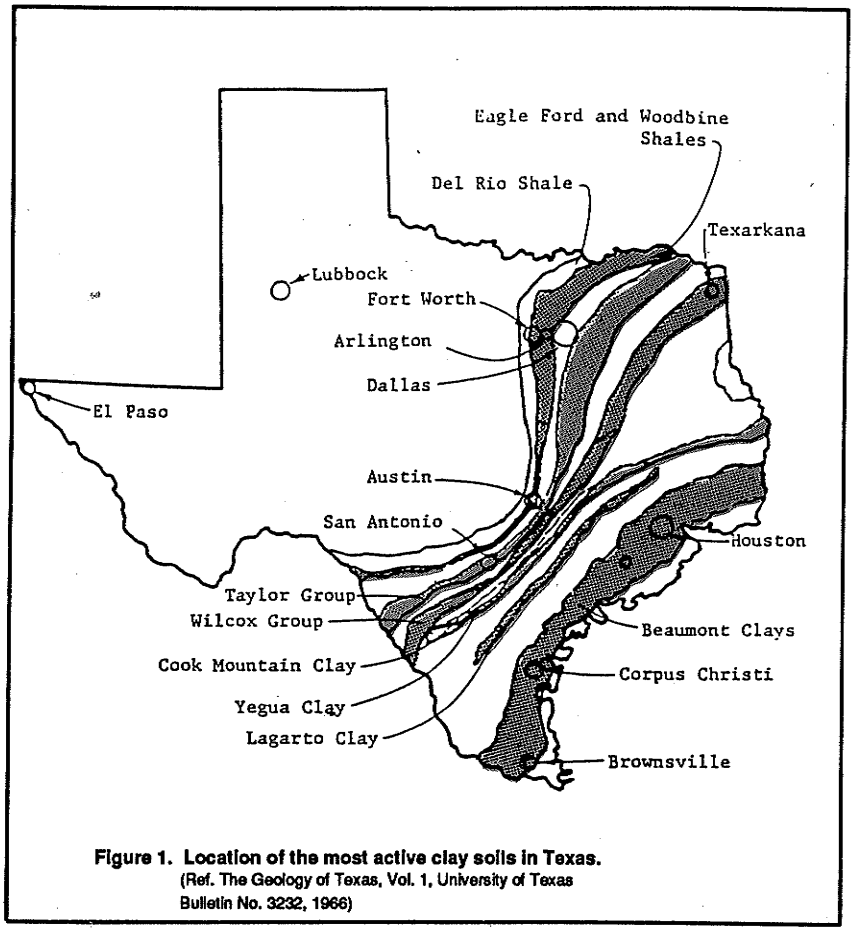
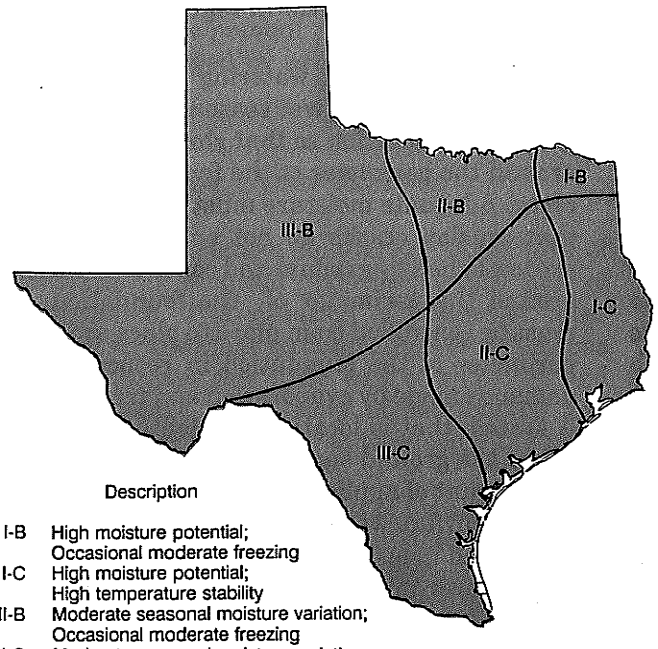


Figure 1. Location of the most active clay soils in Texas.
(Ref. The Geology of Texas, Vol. 1, University of Texas Bulletin No. 3232, 1966)



Description

I-B	High moisture potential; Occasional moderate freezing
I-C	High moisture potential; High temperature stability
II-B	Moderate seasonal moisture variation; Occasional moderate freezing
II-C	Moderate seasonal moisture variation; High temperature stability
III-B	Low moisture potential; Occasional moderate freezing
III-C	Low moisture potential High temperature stability

Figure 2. Climatic zones in Texas.

the Dallas-Fort Worth metropolitan area and experiences moderate seasonal moisture variation. This means generally that there is a wet period in the spring followed by a hot, dry summer. The climate zones ending with "B" have occasional moderate freezing, while those further south and ending with "C" have high temperature stability and generally remain above freezing.

Slopes

Slopes create special problems for residential structures. There is often inadequate or nonuniform compaction of fill in creating a building pad. This may result in movement of the soil as it settles with time or loading and erosion following construction. Drainage is more difficult to control due to the need to "cut into the slope" to locate the house. In addition, slow downhill movements of slopes of expansive clays have been noted on slopes as small as 6 percent.

Expansive clay soil requires the homeowner to consider not only the foundation and home, but also the site, the soil and the climate in order to have a system that works well. Effective home maintenance for this problem can be achieved through watering, landscaping and drainage, and gutter and drain systems. These components will be described in the sections that follow.

WATERING

Watering of landscaping and the area around the foundation can be effective when the foundation is located on expansive clay soils. Consistent but moderate watering can change the effects of moderate or severe moisture variation, to one of relatively constant moisture conditions. However, watering requirements are greater in the vicinity of trees than they are in grassed areas.

Watering should be conducted in a systematic and scheduled manner. This watering is not just to keep the grass green — it is to maintain moisture stability and uniformity and prevent volume changes for the clay soil! As a side benefit, the grass and landscaping will thrive.

Watering needs for the newly constructed home should be considered at the time a foundation is built. For homes that already exist, a history of watering and landscaping has already affected the structure and the underlying soil. This history must be considered in determining the future maintenance of the foundation. Watering needs for newly constructed and for previously maintained homes will be described in separate sections so that the important considerations are clarified.

Newly Constructed Homes

The purchaser of a newly constructed home usually is able to obtain construction information from the builder. For consideration of watering needs, it is important to know at what time of year the foundation was placed. The simplest way to find out is to ask the builder. Another method is to check the date of the foundation inspection with the city inspector's office. Most municipalities require a building permit and inspection of the placement of steel in the foundation prior to placement of concrete. Records are available in the building permit/inspector's office.

If construction of the foundation took place immediately following the wet season, the shrinkage crack structure of the soil would have been closed due to swelling of the clay soils during the rainy season. The soil would be in a condition of maximum natural moisture. The soils in Texas, even following the wet season, are drier than they could be, but construction at the end of the wet season seals in the naturally available water. No evaporation can take place from the area that is covered by the slab, but evaporation and transpiration through grass, shrubs and trees will occur around the edges. If moisture loss continues to occur around the edges, drying will extend inward from the edge of the foundation, shrinkage along the edges will occur, and a domed shape will occur under the foundation. This type of foundation deformation is sketched in Figure 3 and labelled "edge drying."

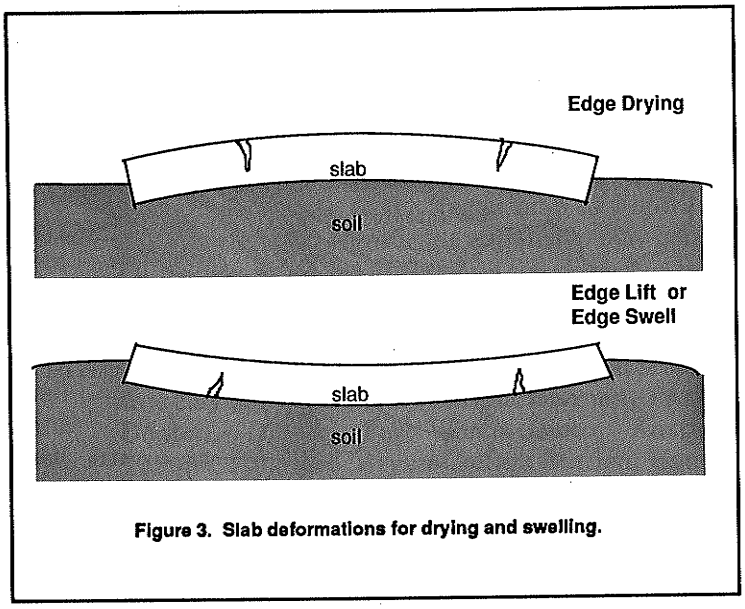


Figure 3. Slab deformations for drying and swelling.

Thus, the goal of watering for a foundation placed following the wet season is to compensate for edge evaporation so that shrinkage of the soil around the perimeter of the foundation does not occur. Adequate moisture must be maintained so that tension cracks do not open. This may be accomplished by gradual and consistent watering around the perimeter of the foundation. This must be controlled from place to place around the perimeter of the foundation in response to the demands made by evaporation and transpiration. A system that is located at a depth of 18 inches below the ground surface may be used to reduce the amount of applied water that is lost to evaporation. Surface watering, while less effective, may be applied using a slow drip hose system with a mulch cover to reduce evaporation loss.

Use of a horizontal barrier may also be effective in reducing moisture loss around the perimeter of the home. The horizontal barrier may consist of a concrete sidewalk type of structure or an impermeable geomembrane placed next to the foundation. Barriers of this type have not found signifi-

cant use in the United States because of our concepts of landscaping immediately adjacent to the foundation, but they have been used in areas of Australia having similarly expansive clays. Installation of a horizontal barrier is worth consideration for a new home when landscaping plans are flexible.

It is common to discover that the foundation of a newly constructed home is placed following the dry season, (e.g., during the summer months) when a fully or partially developed system of cracks exists in the clay soil, both in the horizontal and vertical direction. Water movement in the cracked clay occurs in the cracks, which allows water to enter the soil much faster than it could without the crack system. For a foundation placed on the dry soil, the crack structure of the soil extends under the entire foundation. Subsequent wetting, either from rainfall or from watering, will tend to enter the crack system around the perimeter and move in the cracks toward the center of the structure. Swelling of the clay is likely in the soil around the perimeter, resulting in a cup shaped slab deformation. This is shown in Figure 3, labelled as "edge swell."

Unfortunately, it is impossible to control rainfall, so the homeowner is unable to maintain the uniform dry condition. Instead, the condition of moisture equilibrium must be achieved by gradual wetting despite the initial dry conditions. Once this condition is reached, maintenance watering must be done to prevent reformation of the crack structure followed by rewetting during the next rainfall.

Pre-owned or Older Homes

Achieving moisture equilibrium is the goal of the watering program regardless of the time of construction. The situation is somewhat more difficult for the older structure, however, because the homeowner has little way of knowing, and cannot change, the history of landscaping and maintenance that has already affected the foundation of the home.

A short list of typical signs of foundation damage is shown in Table 1. In considering an older structure, the condition of the structure should be compared to this list. If the structure has no signs of foundation damage and is well-maintained with obvious watering of landscape, then the moisture control used in the past has been adequate to achieve and maintain moisture equilibrium. In this case, inquire of the previous owner the method, frequency and duration used for watering and adopt this watering method if possible. That is, find out what type of sprinklers were used, how often watering was done, and for how long the watering was continued during each watering.

Many older homes do show signs of some foundation damage. In this case it is important to discover the likely cause. Two causes of significant damage are plumbing leaks and leakage from a swimming pool or installed landscape watering system. Plumbing leaks and other sources of water must be repaired promptly. Seek the advice of a professional engineer if the cause is not clear. Cosmetic repairs will not be effective unless the cause of the cosmetic damage is corrected.

Following repairs, water to achieve moisture equilibrium and use regular maintenance watering to maintain the moisture condition once equilibrium is achieved. Otherwise the damage will reappear and the repair process will have to be repeated.

It may be necessary to install a root barrier between trees and the foundation because moisture equilibrium is nearly impossible to achieve near trees. A more detailed description of a root barrier is included in the section on landscaping.

Table 1. Typical Signs of Foundation Damage

1. Cracking of exterior brick veneer that varies in width from top to bottom or diagonal cracks. (Cracks of uniform width are commonly shrinkage cracks and do not indicate expansive soil activity.)
2. Separation of expansion joints.
3. Cracks above or below window and door openings inside home.
4. Visible cracking of foundation slab.
5. Inability to open or close doors. Doors of rooms, closets or cabinets out of alignment.
6. Cracking or waving of floor finishes. Most often visible in linoleum tiles or ceramic tiles.
7. Feeling of walking up or down hill as you walk across room. (In fact, you are!)

LANDSCAPING

It is important to control the location and watering of vegetation around the home. The primary components of typical landscaping include trees, shrubbery, and grass/flower gardens. All types of plants will establish roots under a foundation if necessary in order to satisfy their moisture requirements. It is important, therefore, to plan not only the selection and planting of landscaping components, but also the maintenance of the established lawn.

Trees are the first landscape component and offer the clear benefits to the homeowner of shade, energy conservation and improved home resale value. However, several researchers have shown that tree roots have a serious effect on subgrade moisture and cause foundation damage. It is necessary to balance the desirability of trees against the damage they may cause.

If a tree had a well established root structure prior to placement of the foundation, has no roots under the foundation, but has been watered adequately following construction, it can exist with little damage even if located in close proximity to the foundation. It is important to provide adequate moisture for the tree root system so that the tree will not put out new root growth under the foundation in order to satisfy its water requirements. One method to encourage root growth away from the foundation is to water trees on the far side of the tree instead of between the tree and the foundation.

If the roots of the tree extend beneath the foundation, it will cause movement and some degree of damage regardless of the consistency of watering. A root barrier can be installed between the tree and the foundation to prevent severe damage. The root barrier should be placed as far from the tree and as near to the foundation as possible in order to decrease damage to the tree roots. Such a barrier is normally 4 feet deep, since the majority of the volume change occurs in the upper 4 feet of the clay.

A root barrier consists of a barrier material placed in a 4-foot deep trench extending along the foundation between the tree and the foundation. The barrier may be constructed of concrete reinforced with wire mesh to prevent tension cracks from developing. If joints are formed in placing the concrete, then rock salt must be placed both inside and outside the joint in order to repel the tree roots without causing damage to the tree. An alternate material for construction of a root barrier is corrugated fiberglass, available in convenient 4-foot by 8-foot sheets. Six-inch overlaps must be provided, with rock salt along the inside and outside of the overlap. A schematic of a root barrier is shown in Figure 4.

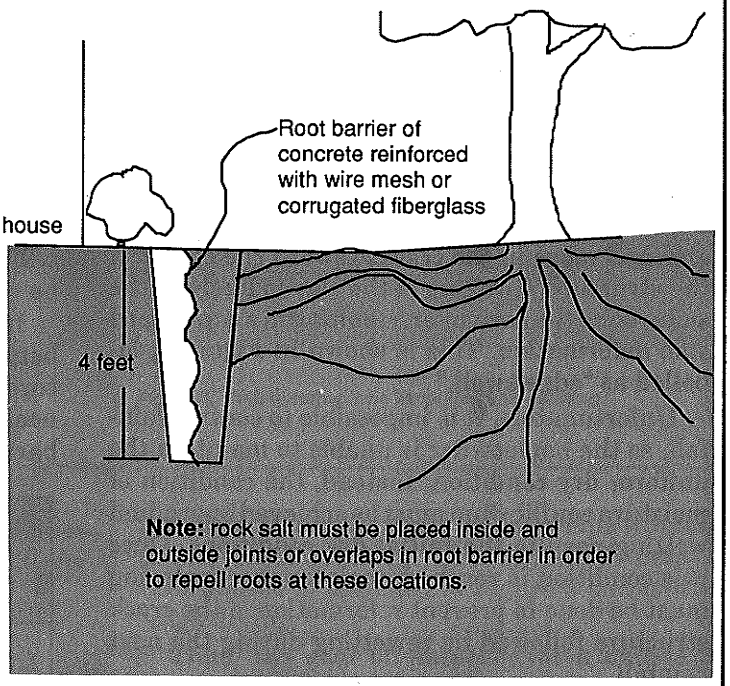


Figure 4. Root barrier to prevent root intrusion under foundation.

There are two aspects to new trees that the homeowner should consider: selection of **type** and **location**. Select trees that are characterized by a deep tap root system as opposed to surficial roots. The surficial roots cause damage not only to the foundation, but also to driveways and sidewalks which they lift and crack.

New trees should be located at a sufficient distance from the home to prevent root damage. Surface roots noted growing toward the foundation should be removed. To be on the safe side, locate trees at a distance 1.5 times the expected mature tree height from the foundation. In reality, this is further than can normally be done and achieve the benefits of shade. As an alternative, a root barrier like the one just described can be installed at the time the tree is planted to eliminate damage from surface roots.

Providing adequate moisture is essential to prevent root damage. Observations have shown that damage is most severe in the portions of foundations located near trees indicating that tree moisture requirements are often not met. Neil Sperry suggests use of a spike watering system or a slow drip irrigation system around the base of each tree in order to provide adequate moisture. Water should be added to trees on the side farthest from the foundation in order to encourage root growth in that direction. Local reputable nursery personnel should be able to estimate moisture needs of trees and to recommend strong tap root varieties suitable in a particular area. Another valuable source of this information is your local county Extension agent.

DRAINAGE

Soil Slope

Maintaining good drainage is often a forgotten aspect of home maintenance, but it is essential in order to prevent areas of moisture concentration that will result in damaging differential swell of the clay soil. The home-owner must assure that no ponds or pools of water are present around the foundation of the home, and correct the drainage at locations where water does accumulate.

At the time of construction, the contractor is normally required to provide soil slope according to the building codes of a particular area. A typical building code requirement might be a slope of 1 vertical to 12 horizontal for the soil within 6 feet of the edges of the foundation. Having this type of ground slope is called providing positive drainage. This assures that rainfall and roof runoff flows away from the house. While these slopes are typical, homeowners can find out the specifications for new construction in their town by contacting the building permit and city inspection office.

Over a period of time this desirable ground slope may be lost due to landscaping, structural additions, and other modifications. Other causes of changes in the ground slope will be erosion of bare soil and hole-digging by family pets.

Restoration of desirable ground slope is an important maintenance task and is one that most homeowners can accomplish without needing a contractor. The tools for the job include shovels and a wheelbarrow, and a hand compactor, which is desirable if layers of soil greater than 6 inches are required. Building a cross-section template, like that shown in Figure 5, from 2-foot by 4-foot lumber or cut from a sheet of plywood, is helpful for assuring that the desired slope is achieved. Using the template allows the homeowner to check each slope objectively. The template can be used repeatedly as progress is made around the foundation.

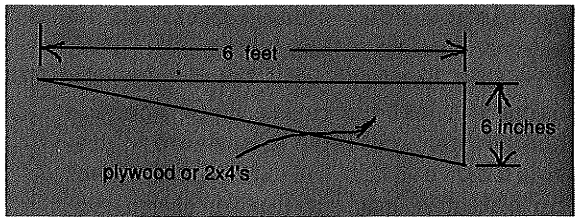


Figure 5. Template to check soil slope around foundation.

In providing adequate slope, soil should not be placed above the top of the foundation concrete. That is, do not raise the level of the soil to or above the lower level of the brick veneer. Infiltration of moisture and fine soil into the house and into the insulation material may occur if soil is raised to this level.

The homeowner must also use care if soil is to be added around existing trees. Consult Sperry's book or a reputable nursery concerning methods for protecting trees from raised soil levels.

Following the completion of the project of providing adequate soil slope, all bare soil should be planted with grass or otherwise protected from erosion. While the project of creating good soil slope is within the ability of most homeowners, it is not a project that most people would like to redo following the next rainfall!

Gutters

Gutters are used to centralize collection and removal of roof runoff. It is imperative that the gutter downspouts be directed to positive drainage. Water accumulation at the base of the downspout will cause localized soil swelling, just as a tree root system can cause localized soil shrinkage. The goal is to extend the downspout away from the foundation so that the foundation is not affected by the discharged water.

A variety of materials can be used to add an extension to downspouts. The most common is a straight section of gutter material that is connected to the existing downspout. While these extensions are effective for drainage purposes,

they are susceptible to crushing and disconnection during mowing and other activities. Home maintenance includes not only installation of the extension, but periodic inspection to see that the extensions are properly attached.

Another relatively common extension is the continuous concrete trough that extends several feet from the edge of the foundation. The same effect can be achieved using a 2-foot length of PVC pipe that has been split lengthwise. In using the less expensive PVC pipe, the homeowner will have to use care to provide a brace so that the extension does not tip out of alignment during storm discharge. The concrete troughs are heavy enough that stability is not a problem once they have been properly placed.

Another commercially available extension consists of a retractable hose that connects to the downspout. Water pressure during rainfall causes the hose to unroll and the water is sprinkled over a fairly large area. This is acceptable for a house having good positive drainage as previously described. Clogging of the holes in the extension may result in water backing up and ultimately bursting the connection between the extension and the downspout. Cleaning the extension periodically is required maintenance for this system.

One additional method of collecting and distributing water from gutters is to have the downspouts connect to an underground plumbing system that connects to a storm sewer or otherwise exits at a significant distance from the house. This is a much more expensive option and would normally be installed at the time of home construction.

One location that causes significant difficulty in moving gutter discharge away from the foundation is for gutters in a courtyard entrance. These courtyards are relatively small in size and often have decorative brick walls extending part of the way across the open side. A gutter system is usually included so that rainfall does not pour off the roof at the entrance. Unfortunately, the downspout often is located inside the courtyard and invites water to pond causing localized swelling. Atriums can have similar problems.

Homeowners faced with this condition should consider extending the gutter system around the edge of the courtyard and moving the downspout to beyond the courtyard walls. Before and after sketches of a typical courtyard with gutters are shown in Figure 6.

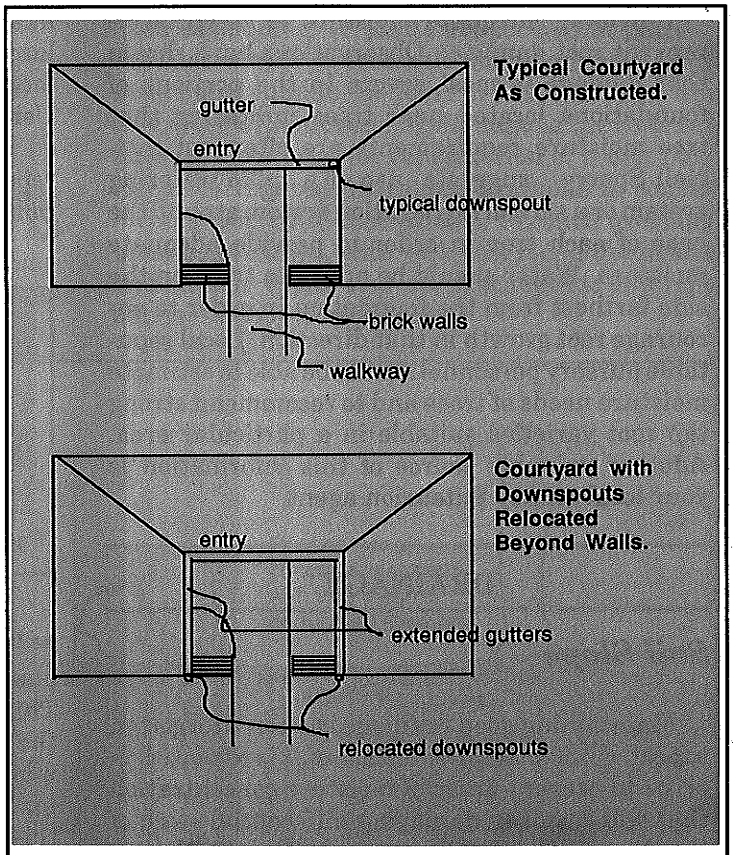


Figure 6. Typical and desirable gutter downspout locations for courtyards.

Drain Systems

Surface Drains

Drain systems may be installed to maintain or achieve drainage of low-lying areas or to intercept water before it reaches the soil adjacent to the foundation. Drain systems are designed by a professional engineer or architect and are normally installed by a professional contractor. Most cities require a building permit and inspection of the drain system. Fees are usually associated with tying in with city storm sewer systems, and there are restrictions concerning other acceptable methods of discharging water from the drain system. This discussion, therefore, is aimed at improving the homeowner's understanding of what the drain is supposed to do. It is not intended to provide a "how to" since this project is beyond the scope of typical residential foundation maintenance.

Installation of a drain system provides drainage when positive drainage cannot be achieved by simply modifying soil slope. A simple drain system for a low-lying area will consist of a sump and a method of discharging water that accumulates in the sump. A sump is simply a low area, often a trench or a central hole. The size of the sump depends on the amount of water expected to drain into the system during peak rainfall. This is calculated based on the size of the drainage area, which often extends beyond the property line; whether the drainage area is paved or unpaved; and the magnitude of the peak rainfall used for the design of the system. The shape of the sump depends on the size and shape of the area to be drained, though rectangles and trenches are common.

The sump is filled with gravel to allow free movement of water into the pipe or pump removal system and to provide lateral stability so the walls of the sump do not slough off. Various sizes of sands and gravels may be used to provide a soil filter to prevent movement of small soil particles into the drain causing it to clog. Geofabrics (man-made porous fabrics that do not decay) may also be used to provide the soil filter.

Water which collects in the sump is either pumped to an acceptable discharge location or enters a perforated pipe which carries the water to a storm sewer system. In rural areas, discharge by pumping into a well-drained pasture is common. In more urban areas, there are restrictions concerning methods of discharging and these would be incorporated into the design process.

Subsurface Drains

Subsurface drains may be required in areas where there are horizontal lenses or thin layers of sand in the soil and on slopes which carry water beneath the foundation unless intercepted. Detection of this problem normally requires consultation with a professional engineer or soil scientist.

The drain system would consist of a gravel-filled trench extending deep enough to intercept the water-bearing layer(s). A slotted or perforated drainpipe collects water from the subsurface drain and carries it to a storm sewer or to daylight. Use of a pervious geofabric to act as a filter is common, and an impermeable geomembrane may be used on the foundation side of the trench to hold moisture under the foundation. A schematic of a typical subsurface drain is shown in Figure 7.

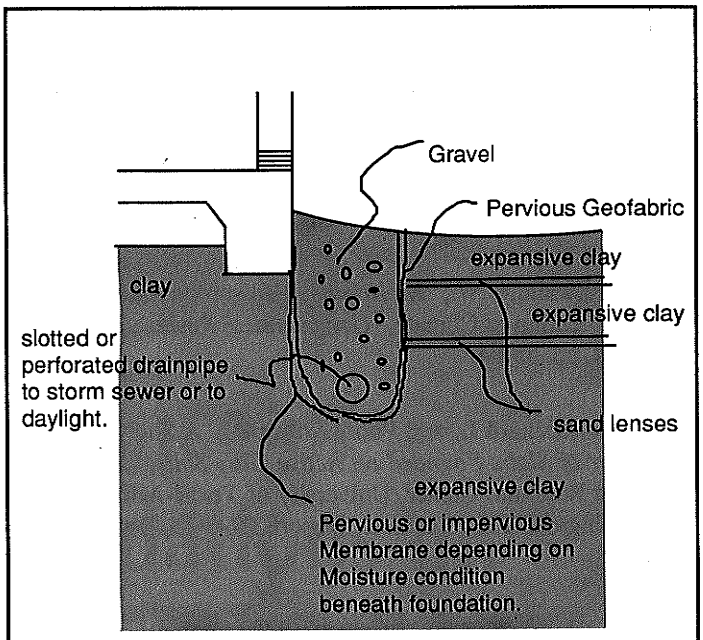


Figure 7. Typical subsurface drain system.

Installation of drains is relatively expensive and is used only when other methods of providing adequate drainage are ineffective. If a drain system is installed, the homeowner should check the discharge periodically to assure that the drain system has not clogged up. If the system is no longer working, the sand and gravel in the trench must be removed, cleaned, separated by size and replaced. Often it is more cost effective to remove the sand and gravel and replace it with new material having proper particle sizes. During cleaning it is usually necessary to perform maintenance on the pump or to clean the discharge pipe.

REFERENCES

1. Davis, Robert C. and Tucker, Richard L. "Soil Moisture and Temperature Variations Beneath a Slab Barrier on Expansive Clay" Research Report TR-3-73, Construction Research Center, University of Texas-Arlington, Arlington, TX, May 1, 1973.

2. Picornell, M. and Lytton, R.L. "Modelling the Heave of a Heavily Loaded Foundation," *Proceedings of the Fifth International Conference on Expansive Soils*, Adelaide, Australia, 1984, pp. 104-108.

3. "Site Instrumentation and Monitoring of Damaged Buildings in Amman and Irbid," from the Seminar on Buildings on Clay Soil in Jordan, Royal Scientific Society, Amman, Jordan, February 20-21, 1983.

4. Sperry, Neil, *Complete Guide to Texas Gardening*, Taylor Publishing Company, Dallas, TX, 1982.

5. Thornthwaite, C.W., "An Approach Towards a Rational Classification of Climate," *Geographical Review*, No. 38, 1948, pp. 55-94.

6. Tucker, Richard L. and Poor, Arthur R., *A Study of Behavior of Slabs Founded on Active Clay Soils*, Construction Research Center, University of Texas-Arlington, Arlington, TX, Research Report TR-5-73, 2 volumes.

7. Wray, Warren K. "The Effect of Climate on Expansive Soils Supporting On-Grade Structures in a Dry Climate," *Transportation Research Record 1137*, Transportation Research Board publication of *Soil Mechanics Considerations in Arid and Semiarid Areas*, Washington, DC, 1987.

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