Expansive soils have created problems for structural and geotechnical engineers for as long as engineers have evaluated soils and foundations. While engineering literature has addressed and studied expansive soils for years, there is still a lack of understanding, and a certain mystique, regarding practical application within the design and construction community regarding their behavior.

The Mystery

By: Gary P. Ten Eyck, P.E. & James T. Slider, P.E.

"The shrink-swell behavior of the clay soil will cause the supported slab or structural element to move, as it is in direct contact with the supporting material."

Expansive soils occur in nature throughout the entire country to some extent, typically in isolated areas. However, most of Texas, Oklahoma and much of Colorado are "blessed" with expansive soils. As a result, successful projects result when designed and constructed to:

- Avoid the predictable effects of the clay soils.
- Mitigate the differential movement/forces imparted to the structure.
- Resist the forces imposed upon the structure.

What are Expansive Soils?

Typically, clay soils exhibit some expansive characteristics. Clay soils are composed of thin, flattened particles less than 0.005 mm. As the ratio of surface area to particle size increases, so also the attraction of free moisture increases resulting in a gain of volume, or swelling. Montmorillanite and bentonite are two types of clays that exhibit the greatest capability to absorb moisture.

The potential for expansion and the resulting forces generated are very large. In the central Texas area, upward movements of 6 to 8 inches or more, and forces of several tons per square foot, are not uncommon. The potential for expansion is referred to as potential vertical rise (PVR), and the measure of a clay materials propensity for expansion is termed the plasticity index (PI). Clays with PIs less than 20 are only marginally expansive, while clays with PIs greater than 40 are considered to be highly expansive.

Effects of Expansive Clays on Foundations

If the moisture content of expansive clays remained constant, no movement (shrinking or swelling) would occur. This rarely happens in nature. It is the differential change in moisture content that activates the shrink or swell characteristics of clay soils, resulting in differential movement, damage and distress. Factors that cause changes in moisture content include, but are not limited to groundwater, landscape irrigation, poor drainage, leaking pipes, trees, landscape planting, seasonal, or extended, wet or dry periods.

Ground-supported slab foundations for residence and light commercial building are flexible systems and tend to conform to the shape of the underlying soils. As the supporting soil changes moisture content, the clay soils respond and swell with gain of moisture or shrink with loss of moisture. The shrink-swell behavior of the clay soil will cause the supported slab or structural element to move, as it is in direct contact with the supporting material. With differential foundation movement, tilt-wall panels can be lifted from their supports, wallboard cracks, brick veneer cracks, skewed door and window frames, and other damage or distress will occur.

In areas of highly expansive clays, it is typical to see differential foundation movement result in either an elevated center of the slab, a characteristic generally known as center-lift, or an elevated or declined perimeter of the slab, a characteristic generally known as edge-lift or edge-

"…the foundation perimeter may fluctuate up or down in elevation."

# of Expansive Soils

Stair step cracking in brick veneer

decline. Generally, center-lift is considered to be the result of long-term soil moisture gain and is associated with older foundations. Edge-lift and edge-decline is considered to be the result of seasonal or otherwise transient influence that results in the gain or loss of moisture. As the soil around the building experiences a change in moisture content due to seasonal climatic conditions, the foundation perimeter may fluctuate up or down in elevation. In general, a seasonal moisture loss would cause the soil to shrink and allow for downward displacement of the foundation. Conversely, a seasonal moisture gain would cause the soil to swell and allow for upward movement of the foundation perimeter.

Designing Foundations in Expansive Clay Soils

Varieties of foundation types are used in expansive clay soils. If slightly expansive material occurs, and when the owner elects to accept an element of risk, simpler grade supported foundations are commonly used. As the soils become more expansive or the building type more sophisticated, owners are less willing to risk movement and distress, and more effective and expensive foundations are required.

Grade Supported Foundations

These are more commonly used in low or moderately expansive soils, and for residential or light commercial buildings where the owner has accepted the risk of damage and distress due to differential foundation movement. They are usually formed with a grid of footings in each direction, and are post-tensioned or conventionally reinforced. If the foundation is sufficiently stiff (deeper and more closely-spaced ribs), it can perform fairly well. However, even with the best precautions, some differential movement and resulting cosmetic distress may occur. Often these foundations are supported on two or more feet of select fill, or on a water injected sub-base. These techniques are effective in minimizing movement potential.

Drilled Pier Foundations with Interior Slab-On-Grade

This is the most common type of foundation utilized for buildings on expansive clays. All load-bearing elements, columns, walls, etc., are supported on grade beams and piers isolated from the subgrade to prevent the action of expansive clay soils from exerting force on the beam or pier. Belled, or under-reamed piers can be used to transfer structure loads to an appropriate bearing strata located below the depth of seasonal moisture variation, typically a minimum of 15 feet, or deeper. The bell also serves to anchor the pier from being uplifted by the active clays. In areas where rock is available at an economical depth, or for higher loads, straight shaft piers are anchored into the strata. The anchoring into rock resists the uplift forces from the clays and can be used to resist part of the vertical load through skin friction. The grade-supported slab is supported on several feet of select fill, or a water-injected sub-grade, to reduce the effects of the expansive nature of the sub-grade.

Dilled Piers and Suspended Slab

This is the most expensive system and is used when movement of the slab cannot be tolerated. Often a beam and slab system is constructed on carton void-forms to isolate the slab or structural element from the expansive subgrade. The drilled pier system would be the same as that described above.

Interior Settlement

Foundation additional separation

Commercial office building foundation failure

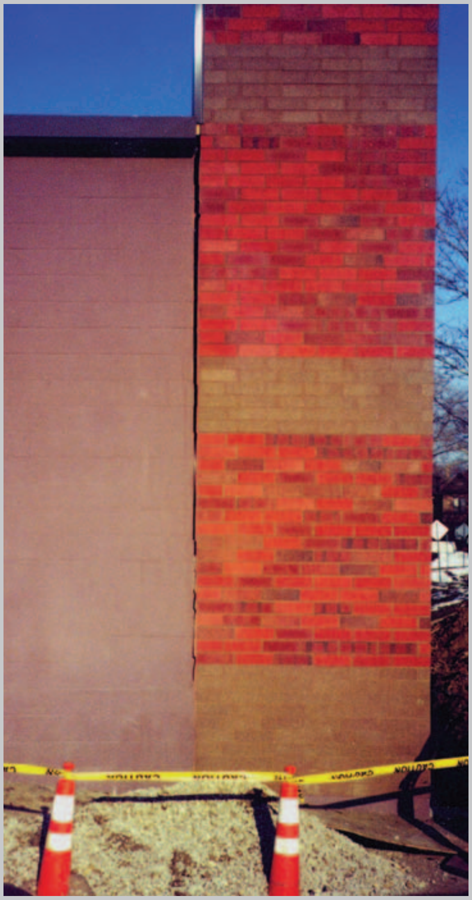
"...address the causes for differential moisture..."

Evaluating Damage and Making Repairs

Despite the best design intentions, expansive soils often fail to cooperate and movement related distress occurs. This most commonly occurs in ground-supported foundations. The first line of attack is to address the causes for differential moisture, and to stabilize the moisture content of the supporting clay soils. Typical remedies to address variations in moisture content include revising the drainage characteristics of the surrounding site, repairing plumbing leaks, installation of moisture barriers, root barriers to isolate and maintain in-situ moisture content of the supporting subgrade from the effects of seasonal moisture changes, desiccation effects of vegetation, etc. Secondly, it may be necessary to level the structure by installing drilled piers below the foundation or by pressure injection of cement slurry, urethane, etc. It is important to note that all of these remedies mitigate or temporarily modify damage and distress resulting from differential foundation movement, and only effect temporary "leveling" of the supported structure.

Distress to structures supported upon properly designed and constructed drilled pier and suspended slab foundations is less common. If the supporting piers are not properly anchored, they can be lifted; or, if the pier vertical reinforcement is not adequate the uplift forces can actually pull the pier apart. The forces associated with the expansion of clay soils are very high, and even the full dead load of the structure is usually not adequate to resist them.

Stair step cracking in brick veneer



Foundation settlement (leaning wall)

> ***"...uplift forces can actually pull the pier apart."***

For suspended slabs, if the depth of the void space is not adequate, the expansive clays can fill the void and exert an upward force on the supported structural element or foundation resulting in distress or damage. Repair options include replacing the structural element if sufficiently damaged or excavating and reconstructing an appropriate void. Neither solution is inexpensive.

Summary

Most properly designed and constructed foundations in expansive clays perform well. However, failure to consider the effects of soil-caused movement can result in a "disastrous" situation. The key to a successful design is close cooperation between the geotechnical and structural engineer, the contractor's adherence to the plans and specifications, sufficient experience, and a healthy respect for the forces generated by expansive clays. ▪

Commercial office building foundation stabilization

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