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Getting Control of Expansive Soil

Expansive soil, also called shrink-swell soil, is a very common cause of foundation problems. Depending upon the supply of moisture in the ground, shrink-swell soils will experience changes in volume of up to thirty percent or more. Foundation soils which are expansive will "heave" and can cause lifting of a building or other structure during periods of high moisture. Conversely during periods of falling soil moisture, expansive soil will "collapse" and can result in building settlement. Either way, damage can be extensive.

Expansive soil will also exert pressure on the vertical face of a foundation, basement or retaining wall resulting in lateral movement. Shrink-swell soils which have expanded due to high ground moisture experience a loss of soil strength or "capacity" and the resulting instability can result in various forms of foundation problems and slope failure. Expansive soil should always be a suspect when there is evidence of active foundation movement.

In order for expansive soil to cause foundation problems, there must be fluctuations in the amount of moisture contained in the foundation soils. If the moisture content of the foundation soils can be stabilized, foundation problems can often be avoided. I will be following up on this concept a bit later.

Clay Structure- the Molecular Sandwich

The expansion potential of any particular expansive soil is determined by the percentage of clay and the type of clay in the soil. Clay particles which cause a soil to be expansive are extremely small. Their shape is determined by the arrangement of their constituent atoms which form thin clay crystals.

Clays belong to a family of minerals called silicates. The principal elements in clay are silicone, aluminum and oxygen. Silicone atoms are positioned in the center of a pyramid structure called a tetrahedron with one oxygen atom occupying each of the four corners. Aluminum atoms are situated in the center of an octahedron with an oxygen atom occupying each of the eight corners.

Because of electron sharing, the silicon tetrahedrons link together with one another to form thin tetrahedral sheets. The aluminum octahedrons also link together to form octahedral sheets. The actual clay crystals are a composite of aluminum and silicon sheets which are held together by intra-molecular forces.

There are many other elements which can become incorporated into the clay mineral structure such as hydrogen, sodium, calcium, magnesium, sulfur, etc. The presence and abundance of various dissolved elements or "ions" can impact the composition and behavior of the clay minerals.

For a group of prominent and highly expansive clay minerals called smectites, one octahedral sheet is sandwiched between two tetrahedral sheets to create the mineral structure. In expansive clay, groupings of the constituent clay crystals will attract and hold water molecules between their crystalline sheets in a sort of “molecular sandwich”.

Water Dipoles

Water molecules consist of two hydrogen atoms sharing electrons with a single oxygen atom. The water molecule is electrically balanced but within the molecule, the offsetting charges are not evenly distributed. The two positively charged hydrogen atoms are grouped together on one side of the larger oxygen atom. The result is that the water molecule itself is an electrical “dipole”, having a positive charge where the two hydrogen atoms are situated and a negative charge on the opposite or bare oxygen side of the molecule.

The electrical structure of water molecules enable them to interact with other charged particles. The mechanism by which water molecules become attached to the microscopic clay crystals is called “adsorption”. Because of their shape, composition and resulting electrical charge, the thin clay crystals or “sheets” have an electro-chemical attraction for the water dipoles. The clay mineral “montmorillonite”, which is the most notorious in the smectite family, can adsorb very large amounts of water molecules between its crystalline sheets and therefore has a large shrink-swell potential.

When potentially expansive soil becomes saturated, more and more water dipoles are gathered between the crystalline clay sheets, causing the bulk volume of the soil to increase or swell. The incorporation of the water into the chemical structure of the clay will also cause a reduction in the capacity or strength of the soil.

During periods when the moisture in the expansive soil is being removed, either by gravitational forces or by evaporation, the water between the clay sheets is released, causing the overall volume of the soil to decrease or shrink. As the moisture is removed from the soil, the shrinking soil can develop gross features such as voids or desiccation crack. These shrinkage cracks can be readily observed on the surface of bare soils and provide an important indication of expansive soil activity at the property.

Magic Powder

Expansive clays have the ability to generate tremendous pressure on structures such as concrete foundations. These high pressures are the key to the destructive power of expansive clay in creating foundation problems. I have heard that these pressures can be on the order of 15,000 pounds per square foot. I have a quick story to illustrate the kind of pressure we are talking about.

A number of years ago I built a custom home for my brother the lawyer. He wanted a big pad graded on his hillside lot and when I couldn’t talk him out of it, I hired an Indiana man named Marion to do the grading. In order to avoid foundation problems, we were required to over-excavate so that we could put down a uniform layer of fill.

Marion started in with a big track loader but only a few feet down he started uncovering some rocks that wouldn't budge. Marion was game to try removing the rock and he went at it with tremendous zeal. Unfortunately, he might as well have been trying to move the Rock of Gibraltar. This was not Indiana limestone- it was California blue granite.

We then considered using dynamite but soon discovered a less dramatic solution- we had holes drilled in the rock, poured in a "magic powder" and added water. The next morning the massive granite rocks lay split wide open. The main ingredient in the magic powder was a silicate with oxides of calcium, silicone and aluminum- in other words expansive clay!

Expansion Potential

Potentially expansive soils which can cause foundation problems are identified by soils engineers by measuring the percentage of fine particles in a particular sample. If over 50% of the particles in a sample are able to pass through a number 200 screen or sieve- that is two hundred divisions to the inch- then the sample is classified as either silt or clay or some combination of both. Regardless of the percentage of "fines" in a particular sample, a significant presence of clay minerals in a sample can indicate a possible expansive soil problem.

Clay particles are generally considered to be smaller than silt particles but the true distinction between the two has more to do with origin and shape. Silt particles are products of mechanical erosion and could actually be viewed as very small sand particles. Clay particles are products of chemical weathering and are characterized by their sheet structure and composition.

In order to determine the potential expansion of soils on a particular property, a soils engineer will take representative samples at the jobsite and return them to the lab for testing. Clay soils are often tested to determine their "plasticity index". The plasticity index is a measure of the range over which the clay sample will retain its plastic characteristics. As water is added to a sample of solid dry clay, it will cease to behave like a solid or semi-solid and start to behave like a plastic. The percentage of moisture at that point is the plastic limit.

As one continues to add water, at some point the clay will cease to act like a plastic and start to act like a liquid. That point is called the liquid limit. The plastic and liquid limits of a sample are often referred to as the Atterberg limits after the scientist who defined them. The difference between the plastic limit and the liquid limit is a measure of the plasticity of the sample. Clay which has a plasticity index greater than 50 is considered to be highly plastic. Highly plastic clays are often called "fat clays". Fat clays are usually highly expansive clays.

There are other laboratory tests designed specifically to measure the expansion potential of a particular sample. By adding water to the sample while measuring its deformation, the soils engineer will compare the result to a scale or Expansion Index.

The American Society of Testing Materials (ASTM D 4829) has published a test method and an Expansion Index to quantify the results. The Expansion Index range and potential expansion is as follows:

0-20: Very Low; 21-50: Low; 51-90: Medium; 91-130: High; >130: Very High.

Depending upon your local building code, a soils engineer's report with specified laboratory testing of representative samples from the jobsite may be required to establish the expansion potential of the foundation soils. The building department may require special engineering and foundation construction methods where expansive soil conditions have been verified.

It is important to remember that the soil profile for any particular property may be quite unique. Soil containing cobble, gravel, and sand may also be expansive depending upon the percentage and type of clay in the sample. Depending upon weathering patterns and other factors, near-surface soils may be highly expansive while soils at depth may be non-expansive.

Based upon the soils investigation, the soils engineer should be able to characterize the nature and distribution of expansive soil on a particular project which will aid greatly in the formulation of a cost-effective foundation design.

Confining Pressure and Soil Movement

In order to recognize foundation problems caused by expansive soil, it is necessary to understand the mechanism on the molecular level as I have described it above. Each expanding clay particle contributes to the behavior of the soil mass.

A uniform mass of expansive soil which becomes saturated with moisture will exert pressure in all directions as each individual expanding clay mineral seeks to occupy more space. The direction and magnitude of soil movement will depend upon the magnitude of the confining pressure at any particular point of resistance. Soil movement will be minimized where confining pressures are the largest while movement will be greatest where the magnitude of the confining pressure is the smallest.

As depth increases, the weight of the overburden soil creates increasing confining pressure. Therefore, for any particular uniform mass of expanding soil, the expansion resistance is generally greater at depth than it is near the surface.

On level ground, the magnitude of expanding soil movement will be greatest near the surface and in the upward direction. On sloping ground, the greatest magnitude of movement will again be nearest the surface but the primary direction of movement will also have a horizontal or "lateral" component.

Buildings and other structures which have been constructed on top of a mass of expansive soil create confining pressure which tends to mitigate soil movement. The magnitude of the confining pressure from a building or structure is determined by the load distribution together with other expansion-resisting design elements. When the confining pressure of a building or other structure does not exceed the pressure exerted by the expanding soil, foundation movement will occur on the form of "heave" or upward movement.

Differential Heave

In conventional slab-on-grade construction, the continuous concrete perimeter and interior load-bearing footings are founded at greater depth and are more heavily loaded than the concrete floor slab itself. Therefore, expansive soil acting uniformly on a slab-on-grade building will generally encounter more resistance from the continuous footings and less resistance from the slab itself.

Assuming that moisture is uniformly adsorbed by a mass of expansive soil, the magnitude of any resulting heave will be greater for the lightly loaded slab than for the more heavily loaded perimeter footing. This pattern, called "differential heave", can be observed and measured with a floor-level survey and plot. I have seen it over and over again on California homes constructed on expansive soils.

For a typical single-story building with truss roof system, the pattern of contour lines defining differential heave will often illustrate a "hump" or mound in the middle part of the floor, where the magnitude of elevation increase at any one point is proportional to the distance from the perimeter footing. Whenever I see the hump pattern on a manometer plot, and after I have considered all other possible explanations, I am usually quite confident that I am seeing evidence of expansive soils acting on the structure.

Humping of a slab which has been caused by expansive soil is often accompanied by multiple cracks which may radiate from the center of the hump. Cracks in walls and ceilings will also be consistent with differential heave.

Another very common sign of expansive soil heave is cracking and lifting of the floor slab of a two-car garage. The high point of the garage slab will usually be near the mid-point of the garage door opening. Severe humping at this location will often prevent the garage door from closing properly. This common phenomenon is a perfect illustration of how the location and magnitude of soil expansion will be greatest where the confining pressure is the least.

Differential heave of expansive soil is also a common occurrence for pier and beam foundations. The differences in loading are often between interior isolated piers and continuous footings which usually carry heavier loads. As with the slab-on-grade foundation, uniform wetting of foundation soils can result in a mounding pattern where interior floors have heaved more than the building perimeter.

Patterns of Wetting and Drying

In evaluating damage which may have been caused by expansive soil, one must always consider patterns of wetting and drying of the soil. Soil moisture changes may be due to a rise and fall in the ground water table with the seasons. Soil moisture changes may also be due to periods of unusual rain, changes in humidity or unusual drought. These kinds of changes would be most likely to produce more uniform soil moisture conditions and patterns of foundation movement.

There are also moisture conditions which are caused by other factors such as plumbing leaks, site drainage, and irrigation practices. These conditions can cause differences in the volume of moisture which is being adsorbed by the expansive clay crystals, influencing the behavior of expansive soil and bringing about a variety of foundation movement patterns.

For example, if there is a slow drip or leak in the plumbing system, foundation heave surrounding the leak may be more pronounced. This will show up on the manometer plot as an anomaly which can lead to the location and repair of the leak.

Perhaps because of poor site drainage, the crawl space at one time became saturated due to heavy rains and flooding. Later, because of the effects of sun and wind, the perimeter soils dried more quickly resulting in shrinkage and collapse. The perimeter footing would settle while the wetter soils of the crawl space would keep the interior floor elevated. The floor level pattern would thus reflect the simultaneous effects of shrinkage and swelling of the foundation soils.

Conversely, in a dry climate with a dry crawl space, continuous irrigation around the building perimeter would cause heave of expansive soils and lifting of the perimeter footing while interior floors may remain unaffected. The floor level pattern would then be the reverse of the previous example- high on the perimeter and low in the center.

Lateral Movement and Slope Creep

Expansive soils can also have pronounced effects on site improvements such as patios, walkways, and swimming pools. Because they are lightly loaded, exterior “flatwork” constructed of concrete, brick, and flagstone will quickly respond to soil movement caused by expansive soils. Severe cracking and dislocation of these materials can be the result.

Expansive soils can be particularly brutal to swimming pools and associated improvements. I have seen pools heave, rotate, and crack as a result of expansive soil. Once the cracking begins, the leaking water just feeds the problem. Anyone planning a new pool or planning to repair a pool should consult a knowledgeable pool engineer who will evaluate the soil and design accordingly.

Pavements resting on expansive soils which are also abutted to a building foundation or a retaining wall can move laterally away from the abutting structure while also lifting up, a reflection of the principal that expansive soils exert pressure in all directions. This lateral movement of improvements can be particularly pronounced when there is a nearby slope.

The shrink-swell properties of expansive soils will often cause a phenomenon called “slope creep”. Recalling that there is always a horizontal component of expansive soil movement on sloping ground, the periodic swelling and shrinkage of expansive soils on a slope, together with the forces of gravity, will result in an ongoing conveyance or creep of soil down the face of the slope.

Slope creep can be responsible for distress to on-slope and near slope improvements which can be observed and measured. Walls and fences in particular will rotate in the down-slope direction under the influence of expansive soil. Hillside improvements on creeping soils must be heavily reinforced and firmly anchored to the soil in order to prevent damage and eventual destruction. Design oversight by a qualified foundation engineer is highly recommended.

Design Strategies

In new construction where expansive soil is a concern, the engineer may require controlled pre-wetting of the soil prior to placement of the foundation. This will cause pre-expansion of the soil with the idea that further expansion pressure on the new foundation will be minimized.

Alternatively the soils engineer may recommend that the upper several feet of expansive soil be removed and new non-expansive material be imported and compacted to create a stable layer of soil at the building footprint. Depending upon the severity of expansion potential, non-expansive soils may be mixed with expansive soil to lower the expansion potential to an acceptable level.

Where expansive soil conditions have been causing foundation movement on existing structures, repair designs may include deepened footings, thicker slabs, and extra reinforcing in all concrete foundation elements. Often, "underpinning" may be required to transfer the building loads to deeper and more stable soils.

There are a variety of underpinning methods which include the use of grade beams, concrete piers, pipe piles, screw anchors and a variety of other systems. Underpinning is a separate topic on this website and the visitor is encouraged to go there for a focused discussion of the topic.

The Structural Slab

One common expansive soil repair recommendation for existing slab-on-grade foundations involves the removal of the original concrete slab floor and replacement with a "structural slab". A structural slab has extra thickness and reinforcing to resist movement and distress caused by the expansion pressure of the underlying expansive soil.

Exactly what constitutes a structural slab will depend upon the engineer. In my experience, a structural slab is usually about five or six inches thick and is reinforced with half-inch reinforcing bar (#4 bars) at eighteen to twenty-four inch centers in both directions.

If the existing load-bearing footings are to remain, a concrete saw must be used to cut through the slab, leaving those narrow sections of slab which are directly on top of load-bearing footings. The new structural slab must be connected to the remaining sections of slab with "rebar dowels".

Rebar dowels are pieces of rebar which are epoxy-glued into pre-drilled horizontal holes in the vertical face of the remaining concrete. Drilling is done with a "roto-hammer" or "hammer drill" and must be to a specified depth to achieve the required strength. The epoxy manufacturer will usually specify the hole size and depth required for a particular size rebar.

Depending upon the severity of the expansive soil problem, the engineer may require that soil beneath the proposed structural slab be removed down to a particular depth and replaced with non-expansive material. If such is the recommendation, I will usually ask the engineer to give me an alternative design to see if it may be more cost effective to increase the thickness and reinforcing in the structural slab rather than remove the soil.

Calcium Treatments

There are also expansive soil chemical treatments available which are designed to alter the clay mineralogy and reduce the expansion potential. Treatment with "lime" or Calcium Oxide is the most traditional treatment method. Together with cement and fly-ash, lime is referred to as a "calcium-based treatment". Most commonly used for treating the subgrade on highway construction projects, lime is introduced into the soil in the presence of water.

The lime can cause a reaction called "cation exchange" where "ions" or positively charged atoms in solution are substituted for other species of ion which are attached to the clay mineral crystals.

Lime treatment of expansive soil also causes "flocculation-agglomeration" in which the positive charged ions react with negative charged particles and create other conditions which allow the small clay particles to clump together into larger particles.

Other effects of lime treatment may include the formation of cementing agents within the expansive soil. The net effect of lime treatment is mitigation of foundation problems by reducing in the shrink-swell potential and by increasing the strength of the treated soil.

Alternative Soil Stabilizers

High-sulfate soils do not respond well to lime or other calcium-based soil treatment methods. As a result, highway departments and soils engineering researchers are looking for new and better options. Some of the alternatives which are being tested and tried by highway departments include silica fume, amorphous silica, fly ash, cation exchange products, enzymes, acids, emulsions, and polymers.

Presently there are a number of non-traditional proprietary liquid soil stabilizer products which are being offered for the treatment of expansive soil foundation problems affecting existing buildings and structures. These products may be classified as "ionic" or cation exchange treatments, "enzyme" treatments which involve application of various organic catalysts and "polymer" treatments which utilize both organic and inorganic polymers.

Research on the no-traditional treatment systems is on-going. Due to the magnitude of the foundation problems caused by expansive soil, new and better products are needed. I would caution property owners to get the facts and insist on verifiable results when considering a liquid soil stabilizer.

Moisture Control- Subgrade Irrigation

Toward the beginning of my discussion of expansive soils, I made the following statement: "In order for expansive soil to cause foundation problems, there must be fluctuations in the amount of moisture contained in the foundation soils. If the moisture content of the foundation soils can be stabilized, foundation problems can often be avoided." Moisture control is, in my opinion, an essential and potentially very cost-effective approach to management of foundation problems associated with expansive soil.

The goal in moisture control is to take actions which will keep the expansive soil at a relatively constant level of moisture content. One system which is being used to treat expansive soil is called "subgrade irrigation". The object is to stabilize the expansive soil by injecting moisture into the subgrade.

A program of subgrade irrigation for expansive soil should be designed by an engineer and based upon an investigation of the site and testing of the potentially expansive soil. Subgrade irrigation involves the installation of pipes to conduct water into the foundation soils at various injection points. The amount of water required depends upon the season and the humidity.

Periodic measurement of soil moisture will be required so that the amount of water injected can be adjusted accordingly. The source of water may be a well or the domestic water supply. Subgrade irrigation is an ongoing process should be maintained for the life of the structure.

Subgrade irrigation of expansive soil will usually include the removal of nearby vegetation which could potentially extract moisture from the soil by "transpiration"- the process which accompanies photosynthesis whereby moisture is drawn up by the plant's roots and released through the leaves into the air.

While I have no doubt that subgrade irrigation can be successful in controlling expansive soil movement, I have not been an enthusiastic supporter of this idea. The high levels of soil moisture which are induced by subgrade irrigation can potentially reduce soil capacity. High soil moisture can also accelerate damage to foundation and structural elements such as concrete, rebar and wood framing. Finally, there are ongoing costs and maintenance requirements.

Soil Protection: A Perimeter Apron

Another approach which can be effective in mitigation of swelling and shrinkage of expansive soil involves application of measures to protect the soil mass from excessive wetting or drying. When using this approach, one accepts the existence of the expansive foundation soil and corrective work is focused on drainage-control strategies to keep the soils within an acceptable range of moisture content.

I will often take this approach when dealing with older properties where the damage level has not been too severe and/or the budget for repair is limited. This approach has the twin objectives of intercepting excessive moisture which would cause soil saturation while also shielding the soil from evaporation and other factors which would lead to excessive desiccation.

My favorite which accomplishes both objectives at once is the "perimeter apron". The perimeter apron is a broad protective pavement which is applied to the surface grade around the entire perimeter of the building. All plants and planters are removed. All roof and surface drainage is controlled and directed away from the building.

Having installed the perimeter apron, one has put a covering on the soil surface which diverts all rainfall and drainage away from the foundation soils- mitigating soil saturation. At the same time during times dry periods, the foundation soils are protected from the sun and the wind which tend to suck the moisture out of the soil.

A perimeter apron can be of any durable paving material or "hardscape" such as asphalt, concrete, brick or flagstone. The important thing is that all joints or cracks are sealed up watertight. I do not favor the use of plastic, often placed under a layer of loose gravel, as a perimeter apron. Plastic is too easily damaged and where gravel is used, water will accumulate and drain into the perforations.

The perimeter apron is particularly attractive because it is a duel-purpose improvement- it is both a protective apron and a walkway. Once the apron is installed, there exists an all-weather access around the building. For homeowners who love to have perimeter planters, this is certainly possible as long as the planters are put on top of the hardscape and excess irrigation does not penetrate into the foundation soil.

French Drains and Cutoff Walls

All forms of drainage control can help to mitigate the adverse effects of expansive soil on a property. A French drain or subdrain system can be particularly effective where high water tables and subgrade drainage conditions are bringing high volumes of moisture into the foundation soils.

Simply stated, a French drain is a trench filled with gravel which captures and removes unwanted water. Usually there is a perforated pipe in the bottom of the trench where the moisture accumulates from transport to a discharge point at the end of the pipe. When a French drain is placed around the perimeter of a building, it serves as a barrier to groundwater which would otherwise saturate the foundation soils.

Depending upon the soil conditions, it may also be advantageous to place a "cutoff wall" between the French drain and the building. A cutoff wall is a vertical barrier which prevents soil moisture from moving horizontally- either into of away from the foundation soils.

A cutoff wall may be a concrete wall which abuts or is attached to the existing perimeter foundation. If attached to the foundation, a cutoff wall will transfer the footing loads to deeper soils and as such it also becomes an underpinning system. If underpinning is not required, a heavy plastic liner between the French drain and the building may serve the same function as a cutoff wall.