

Stabilization and Repair of Concrete Slabs-on-Ground Deformed by Expansive Soils

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Abstract

Concrete slabs-on-ground foundation systems may be subject to detrimental deformation due to upward thrust from expansive soils. These deformed slab foundations have traditionally been repaired using methods seeking to overcome the soils' expansive forces through structural means or by complete removal and replacement.

A more cost-effective solution may be reached through the installation of vertical and/or horizontal barriers that re-establish points of origin for moisture intrusion, re-define slab design parameters and stabilize the soil moisture content under the slabs, neutralizing the potential for further deformation.

Introduction

The use of concrete slab-on-ground foundation systems, particularly in residential construction, has been widespread for many years. Slabs-on-ground provide a hard walking surface, eliminate excavation costs and are easy to build.

Design of a slab-on-ground foundation typically involves nothing more than the calculation of line and point loads on continuous and pad footings, which are then sized based on load bearing values from the soils engineer. In a conventional slab-on-ground system, the

slab is typically little more than a walking surface and of not much structural significance.

Design of this nature is adequate for foundation systems on largely stable soils, i.e., neither expansive nor collapsible. The main structural concern is the soils' ability to carry the imposed loads from the structure above. No thought is given to loads imposed by the soils back onto the foundation system.

However, as slabs-on-ground foundation systems were built on expansive soils, the need to address the soils' expansion potential and subsequent deformation of the slabs became apparent. Expansive soils such as clays, have an innate thirst for moisture. Due to their molecular makeup, from a dry to a fully saturated condition expansive soils undergo a substantial volumetric change. The amount of expansion an expansive soil will experience is largely a function of the percentage of moisture present in the soil relative to the moisture possible at total saturation.

Because of this, for a foundation placed on expansive soils with a moisture content below saturation, when additional moisture becomes available it will be absorbed by the soils, with a subsequent expansion in volume. This moisture absorption/volumetric expansion will continue as long as moisture is supplied, until the soil reaches full saturation. The resultant change in volume may deform the slab and cause damage to light framed structures.

Existing Design Methods

The development of structural design methods for concrete slabs-on-ground foundation systems historically followed a trial-and-error empirical approach. As slab designs were used on a more varied spectrum of soil types, adjustments were made based on past performance. This, however, resulted in wildly varying design configurations with no consistent standards or generally accepted design procedures.

Beginning in the mid 1950's, the Federal Housing Authority authorized a technical study to classify slab systems and to develop design methods using soils characteristics. The studies, published by the National Research Council's Building Research Advisory Board for the Federal Housing Authority, became collectively known as the "BRAB" reports. These reports represented one of the first attempts to match climatic moisture conditions and soils characteristics to design intent. The last of these reports (No. 33), published in 1968, established four basic slab types based on functional, soil and climatic conditions.

Since then, a number of distinct and different methods have been developed that take into account some sort of soil/slab interaction. Some of these were created specifically to address vehicular or industrial loads. For residential, office and light commercial uses, five specific methods have emerged as the most-commonly used to generate designs of concrete slabs-on-ground foundation systems on expansive soils. These are:

- Empirical Approach
- Soils Properties Modification
- Isolation Method
- Wire Reinforcement Institute (WRI) Method
- Post-Tensioning Institute (PTI) Method

Empirical Approach

The empirical approach takes many forms, as it is usually based on the engineer's past experience in the general geographical area he/she may be working within. It is sometimes based on the BRAB Report No. 33 construction recommendations, sometimes on those from the PTI. It is not a true "design" method in that there is no structural mathematical analysis used; rather

a slab type is selected from a set of empirically developed configurations based on the soils' expansion potential.

Soils Properties Modification

This method, used on its own or in combinations with one of the other design methods, seeks to revise the need for structural resistance by changing the expansive properties of the existing soil conditions. This is typically done through one of three ways:

- Removal and replacement of expansive material with non-expansive soils.
- Removal and replacement of existing material with existing soils wetted to near saturation levels.
- Chemical treatment of exiting soils to mitigate their expansion potential.

All three of these methods are relatively expensive. The first two are typically used in conjunction with and to reduce design criteria for other design methods. The third is more typically used as a repair approach than as a construction method.

Isolation Method

This method seeks to isolate structural support of the slab from the expansive soils underneath it. The method takes a number of forms, none prevalent in the construction industry because of cost. These methods normally involve the use of a crushable support system under the slab to absorb the soils' expansion.

WRI Method

The WRI Method and the PTI Method are the only two methods specifically included in the Uniform Building Code and the International Building Code for the design of concrete slabs-on-ground over expansive soils. They are the only true structural design methods in that they rely on a mathematical structural analysis to determine the configuration of the slab.

The WRI Method builds on the recommendations of BRAB Report No. 33, taking into consideration either the Expansion Index or the Plasticity Index of the soils (provided by the soils engineer) in addition to

geographical climatic conditions to determine structural design parameters.

The WRI Method assumes a loss of support under the slab caused by movement of the soils underneath. The slab is then designed to span across the area lacking support. WRI Method slabs are rib-stiffened at regular intervals and conventionally reinforced.

PTI Method

In 1976, the PTI funded research at Texas A&M University that included extensive finite-element studies of slab/soil interaction for expansive and compressible soils. Findings from these studies formed the basis for the development of the PTI Method. Although originally developed for use with post-tensioned slabs-on-ground, the findings and the method can be used in the analysis and design of conventional slab-on-ground foundation systems on expansive soils. The PTI Method and the WRI Method are the only two methods specifically included in the Uniform Building Code and the International Building Code for the design of concrete slabs-on-ground over expansive soils.

As opposed to the WRI Method, which assumes a loss of support under the slab, the PTI Method postulates an *excess* of support from expansive soils. In other words, it assumes the soils push up and deform the slab. Moreover, the PTI Method assumes all of the expansive/compressible forces occur within a relatively short distance from the slab perimeter, and puts forth two possible scenarios:

- Center Lift
- Edge Lift

Center lift describes a condition where the slab deforms higher in the center than along the edges. This condition is generally considered a misnomer, in that the typical actual condition that occurs is an edge drop and not a center “lift”. This edge drop is more common in Gulf states along the South, where during dry seasons, trees and vegetation around the slab perimeter draw moisture from the soil, resulting in a volumetric loss. Center lift may also result from the rupturing of a water pipe underneath a slab, but this accidental condition is not typically considered as a design option.

The much more common condition, particularly in the South-Western states, is edge lift, where excess moisture from weather or irrigation percolates inward from the perimeter of the slab. This increase in moisture is accompanied by a volumetric increase in the soils at the slab perimeter, resulting in the lifting of the slab edges.

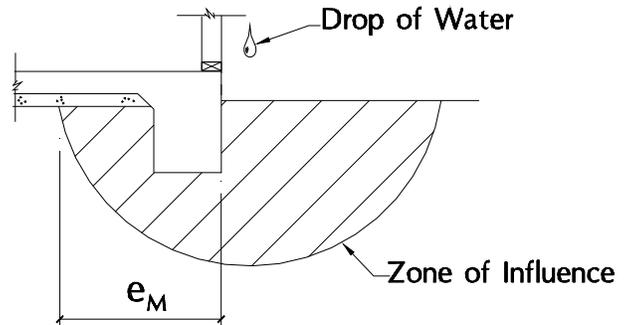


Figure 1. Zone of influence for moisture at slab perimeter and e_m .

Because of clay’s natural affinity for moisture, adjoining clay particles tend to be thrifty with water and will not allow it to travel very freely from one clay particle to the next. As a result, moisture generated at or near ground level travels and results in a change in soil moisture content only down to a specific depth. Accordingly, the PTI Method uses a value e_m , defined as the horizontal distance from the slab edge over which moisture deposited at the edge of the slab will result in an increase in soil moisture content.

Recognition of the Problem

In investigating a potential slab deformation (assuming as in most cases that a base-line slab survey was not done at the time of construction), it is important that three related criteria are analyzed before identifying the problem as expansive soils movement:

1. There must be observable distress to the above-ground structure.
2. The slab surface must be determined to be out of level.
3. A soils engineer must classify the underlying soils as expansive.

Marsh and Thoeny have argued that, for residential slabs over expansive soils, low levels of cosmetic damage appear when slab deformations approximate 1.1". Consistent with this, problems are usually reported by property owners when slab deformations are on the order of 1" to 2", although the reported problems are not typically that the slab is not level. Soils movement will usually manifest itself in the form of interior and exterior wall cracking, doors and windows sticking and roof truss/wall top separations at interior walls.

Where these conditions exist, a laser or water-level survey is necessary to determine if the slab is out of level. Laser or water-level surveys should not be expected to provide exact measurements of past movements. Water-level surveys have an accuracy of +/- 1/4" to 1/2", depending on the operator. In addition, a survey by Walsh reported residential concrete slabs-on-ground at the time of construction typically deviate from level approximately 1/2" to 3/4" throughout the slab. These values should be considered when judging the magnitude of past movement, although not as an excuse to disregard the findings of a laser or water-level survey.

American Concrete Institute (ACI) Publications 117 and 302 present a method for determining a slab's flatness (F_f) and levelness (F_l) by calculating the mean and standard deviations of a prescribed set of measurements. Although espoused by the PTI as the only published standard for determining the levelness of a slab, this "F-number" method does not really provide any more useful information than a water-level analysis. Attempting to use an "F-number" value as the basis for determining whether a slab is performing ignores what may be right in front of you: If movement of the slab is resulting in damage to the walls and ceiling finishes, the foundation system is just simply not doing its job.

Results from a laser or water-level survey would be used to produce a relative elevation contour map of the slab floor. Such a contour map can help identify the over-all shape of the slab, the high and low points and the general magnitudes of the deformations.

For conventional ribbed or un-ribbed slabs, the deformation may be accompanied by cracking a few feet in from the perimeter, generally following the

contours of the water-level survey and roughly centered about the low point. Post-tensioned slabs, ribbed or not, tend to remain whole, with no resultant visible cracking through fairly high slab deformations.

Additional clues that deformations may be caused by the volumetric change of expansive soils under the slab may be obtained from a finer reading of the water-level surveys. At locations of a foundation slab next to a driveway, deformations on the lower range than elsewhere may indicate areas of reduced levels of water intrusion due to the presence of the horizontal moisture barrier provided by the driveway surface. Larger relative deformations near sources of moisture such as planters, hose bibs or rain gutter downspouts, indicate areas of higher water intrusion levels and consequential larger volumetric changes.

Movement can be relative, in that what we typically observe are the effects of the change and not the actual change. It is important to establish whether we are observing the effects of a movement that is upward or downward, as the results can appear very similar.

For an edge lift condition (the most common expansive soil problem) there may be cracking of drywall and stucco surfaces and separation of roof trusses from the tops of interior walls. A laser or water-level slab survey may indicate a floor that is not level, with a deformation that is approximately dish-shaped.

These observations would apply equally to a slab that has deformed along the edges due to edge lift from expansive soils, or to one deformed by the collapse of soils under the center of the slab. Only after the prior two conditions are established and a soils engineer classifies the soils as expansive can one consider a slab deformation as the result of volumetric expansion of clay soils.

Evaluation of the Problem

Once expansive soil slab deformation is identified, the extent of the problem needs to be evaluated in order to determine a repair methodology.

As Marsh and Thoeny reported, residential slabs over expansive soils begin to experience low levels of cosmetic damage when slab deformations exceed 1".

Structural damage to the above-ground structure does not begin to be a real concern until slab deformations exceed 2½”.

This range of slab deformations between 1” to 2½” would form the target range for the repair recommendations presented here.

Larger deformations are entirely possible where the source of moisture is not arrested or where investigation and repair measures are not immediately undertaken. Deformations beyond 3” become much more problematic in terms of repair and require far more aggressive (and expensive) repair methods.

Smaller deformations may not require repair, but some thought should be given to preventive measures. This is particularly true for construction of a repetitive nature, such as tract housing, at other same-slab-configuration locations where deformations within the repair range have not yet taken place.

Detrimental Solution Schemes

It should be said that if the problem is edge lift caused by expansive soils, there are repair solutions that should absolutely not be attempted, as they can exacerbate the problem rather than solve it.

For example, the injection of grout under pressure, a common solution used to repair deformed slabs over granular (non-expansive) soils, should not be contemplated for clay soils. Deformed slabs over granular soils are typically caused by insufficient compaction of the underlying soils, perhaps caused by lack of care during construction, or by a de-densification of the soils due to the washing of fine soluble particles. Pressure grouting re-compacts the soils to a level capable of providing proper support.

However, where clay soils exist, pressure-grouting is analogous to compressing a spring. The compressed spring will expand that much further when additional moisture is absorbed by the soil. The presence of a small percentage of voids between the clay soil particles is actually beneficial as the voids serve to absorb some of the volumetric expansion caused by the introduction of moisture.

Another attempted solution has been the installation of helical piers along the slab perimeter to effectively lock the slab edge in place. Although this solution prevents further movement of the edge, it does not stabilize the moisture level under the slab edge. As that moisture level increases or decreases, the slab areas directly inside the slab perimeter may expand and contract, continuing to cause cosmetic damage inside the structure.

Repair concepts need to take into account the existing moisture level of the expansive soil, the possibility for that moisture level to change and the potential for additional damage. Formulation of any solution needs to be undertaken in a partnership between the structural and the soils engineer.

Formulation of a Repair

Any repair concept should include either the control and stabilization of moisture intrusion or the re-establishment of the point of origin for that moisture intrusion. Where the potential for change in soil moisture content is removed, the potential for future movement is minimized and possibly eliminated.

Past successful repairs have included the removal and replacement of the above-ground structure and the expansive soil underneath it. Chemical treatment of the soils has also been used to change the expansive characteristics of the soil. These methods, though necessary in cases where slab deformations are large enough to result in irreparable damage to the above-ground structure, are relatively expensive and invasive.

Where slab deformations due to expansive soils have resulted in solely cosmetic damage to the above-ground structure or where the potential for such damage exists, two relatively cost-effective solutions are available: a vertical moisture barrier and, a horizontal moisture barrier.

The underlying philosophy with either one of these repair methods is to re-define the existing foundation system as one existing solely to support the loads imposed by the above-ground structure. These repair methods seek to remove the potential for volumetric change of the soils and induce upward pressures back onto the foundation system.

In the case of the vertical barrier repair, this is done by providing a moisture barrier. This barrier would extend down below finished grade to a point where no surface water will have an effect on the soils under the slab. For the horizontal barrier repair, this is done by moving the point of entry a distance e_m (as defined by the PTI) away from the edge of slab. Exterior surface water will potentially only travel a maximum horizontal distance e_m , and will have no influence on the existing soils under the interior slab.

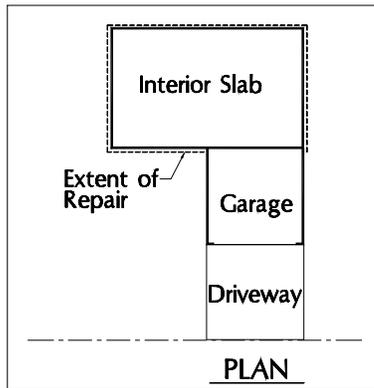


Figure 2. Extent of vertical/horizontal barrier repair for a residential slab.

Choosing either of these repairs requires an assessment by the structural engineer of the condition of the above-ground structural elements, as well as an assessment by the soils engineer of the below-ground conditions. A joint effort from both parties is necessary in selecting the repair that best addresses the existing issues.

Vertical Barrier Repair

The main purpose of a vertical barrier is to maintain constant the existing soil moisture level under the slab. This is accomplished by installing a moisture barrier below ground, just outside the perimeter of the slab.

The depth of the barrier (determined by the soils engineer) is typically extended to just below where moisture generated at or near ground level no longer results in a change in soil moisture content. In this manner, the clay soil’s affinity for moisture helps to seal off the potential for any moisture generated outside the slab to penetrate underneath that slab and cause any further volumetric expansion. At the same time, the

vertical barrier maintains the moisture in the soil under the slab at the existing level, preventing it from migrating outward should there be a drop in the soil moisture level outside the slab. Because the moisture level under the slab is stabilized, the potential for future movement due to volumetric change is minimized and possibly eliminated.

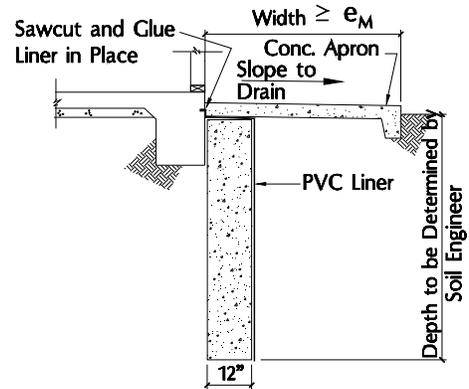


Figure 3. Combination vertical and horizontal barrier.

Vertical barriers can take a number of forms, depending on the requirements of the soils engineer. Some vertical barriers have full-depth reinforced concrete grade beams, tied to the original slab edge, and are designed to help structurally arrest any possible movement of the slab edge. Others may consist solely of a PVC sheet tied to the edge of the slab.

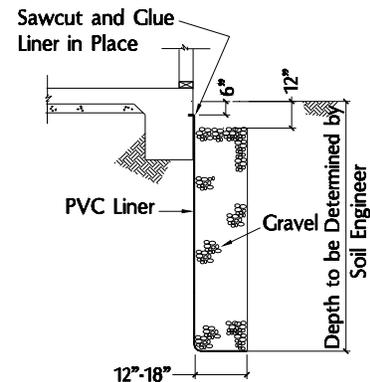


Figure 4. PVC liner vertical barrier.

Horizontal Barrier Repair

In a horizontal barrier repair the main purpose is to re-establish the point of origin for moisture intrusion a distance e_m outside the edge of slab, in other words, beyond the horizontal distance from the slab edge over which surface moisture will result in an increase in the soil moisture content.

This is accomplished through the installation of a horizontal barrier, around the outside perimeter and adjacent to the edge of the slab. The horizontal barrier may involve an on-grade walkway slab or a below-grade barrier, placed at a depth to allow planting against the edge of the slab.

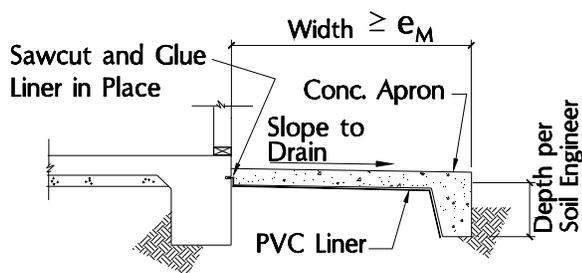


Figure 5. Concrete walkway horizontal barrier.

The width of the horizontal barrier needs to be just larger than e_m and should provide a drainage slope away from the face of the slab. Where an on-grade walkway slab is installed as part of the barrier, consideration should be given to the potential future heave of the walkway (which is now within the soil's e_m), although slab deformations of an exterior walkway are not as detrimental and therefore not as much a source of concern as interior slabs.

Since horizontal barriers re-direct moisture to a point a distance e_m away from the edge of slab, care should be taken for that re-directed moisture not to have a detrimental effect on adjoining structures. Tract houses are generally built with minimal building-to-building separations, and the distance from a building face to the property line may, in some cases, be very close to the e_m value.

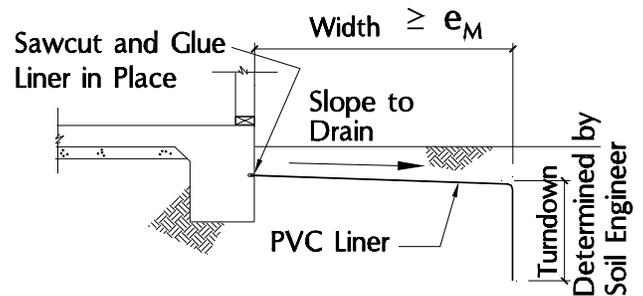


Figure 6. PVC liner horizontal barrier (below finished grade)

Horizontal barriers do very little to help maintain existing soils moisture levels. Thus, they should only be used where the stabilization of those existing soil moisture levels is not a concern. For that reason, horizontal barriers are typically used where soil expansion potentials are on the lower range and where volumetric changes and resultant edge lift have not substantially occurred. Used by themselves, they are more of a preventive measure than a repair. However, at the discretion of the soils and structural engineers and subject to their joint evaluation of the existing conditions, repairs may require the installation of horizontal barriers in conjunction with vertical barriers.

Additional Repairs

Because these repairs are limited to cases where damage to the above-ground structural components are largely cosmetic, no real concern typically would exist in terms of above-ground structural repairs. Cracks and truss/wall separations are usually filled and painted. Where the slabs deviate from level, floors can be brought back to level through the use of self-leveling compounds. Generally the use of these self-leveling fills is limited to the low spots in the slab, extending only as far as necessary to bring the slab within construction tolerances.

For conventional slabs, repairs may include the saw-cutting of interior slabs where slab edges are vertically displaced at crack locations. Dowels would then be drilled in place and a slab strip poured. Where there is no relative vertical displacement of the slab across the crack, epoxy injection would be a repair option.

Attention should also be paid to include in the repairs the elimination of past problem areas, such as enclosed planters adjacent to the slab edge and the re-location of rain water downspout outflows away from the slab edge.

Conclusion

Damage from expansive soils due to volumetric change caused by excess moisture absorption occurs at a relatively common rate. Whether that damage occurs as the result of soils' lack of homogeneity across a site, because of a liberal implementation of design method requirements or to the historical trial-and-error empirical approach, a repair approach needs to exist that can address the problem in a cost-effective manner. Where past repair suggestions have offered either misguided solutions that exacerbate the existing problem or a complete remove-and-replace approach, an understandable reluctance to underwrite the cost of such repairs has only served to delay a solution. This has the additional effect of allowing a bad situation to grow worse, closing the door on simpler solutions and increasing the ultimate cost of repair. In correctly identifying the nature and extent of the problem and in quickly formulating repairs that are reasonable and effective, it is hoped property owners are spared additional stress and can be returned to normal circumstances in a more expedient manner.

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