EXPANSIVE SOILS – IDENTIFICATION, DETECTION AND REMEDIATION STRATEGIES

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Abstract : The phenomenon of Swelling soils in the country is now only slowly being recognized, and Oftentimes only when this has manifested itself in the form of extensive damage to the structures or pavements. Most often, this phenomenon is wrongly attributed to *settlement* and the remedial or response measures are directed to correct the perceived "settlement" which based on the experiences of the Authors do not solve the problem and sometimes even aggravate or accentuate the problem by causing more damage.

Swelling soils are prevalent in the country due to the widespread deposition of Volcanic ash and materials. Because most of the published literature concerning swelling soils are from US sources or from South Africa particularly where these soils occur in dry desert climates, the occurrence of swelling soils in wet tropical climates have been wrongly discounted or ignored often with disastrous results.

This paper seeks to explore and explain the phenomena causing swelling and the attendant damage based on a "local setting" in order to highlight the importance. It has been said that 80% of the solution is in the identification of the problem and this is the focus of the Paper by the authors. The remaining part of the solution, the last 20% is directed towards Avoidance, Defensive measures before construction, as well as Remediation in case the problem has already manifested itself.

1 INTRODUCTION

Potentially expansive soils find wide distribution in the Philippines. The problems are most often unrecognized until it is too late and most often expansion or heaving is misinterpreted as "settlement". Most of the time, damage to facilities and infrastructure is significant and very costly to repair and remediate.

The key to avoidance is early detection and this can be done initially by performing very simple and inexpensive soil index tests.

2 THE FORMATION OF SWELLING SOILS

Swelling soils find wide distribution in areas of volcanic deposition or origin with tropical climate and also in arid and/or semi desert climates. In tropical volcanic settings,

alumina rich volcanic ash gets deposited in general over a wide area. Some get concentrated in depressions or low areas which are almost always inundated or saturated with water. This regular inundation tends to leach the alumina and concentrate these at the bottom 1.0 meter to 2.0 meters generally but could be deeper depending on the leaching effects.

This explains the sporadic occurrence of expansive soils as generally, the expansive soils are not deposited area wide and thus portions of the project footprint may or may not be underlain by these soils.

3 ORIGIN OF SWELLING SOILS

In tropical volcanic environments, volcanic soils rich in alumina is deposited as Aeolian deposits. These Aeolian deposits settle in the land and are thicker in depressed areas. The alumina gets leached and concentrated due to ponding and saturation in the depressed areas. This alumina is the primary source of the expansive tendency and most often are shallow in occurrence due to the limited leveling effects.

4 DAMAGE TO STRUCTURES *(Ref. 2.0)*

(1) *Type of damages.* Damages sustained by structures include: distortion and cracking of pavements and on-grade floor slabs; cracks in grade beams, walls, and drilled shafts; jammed or misaligned doors and windows; and failure of steel or concrete plinths (or blocks) supporting grade beams. Lateral forces may lead to buckling of basement and retaining walls, particularly in overconsolidated and non-fissured soils. The magnitude of damages to structures can be extensive, impair the usefulness of the structure, and

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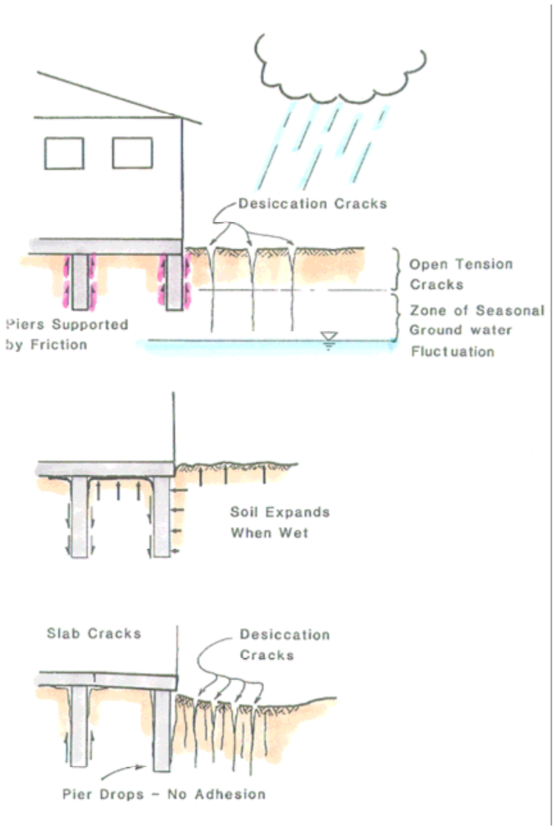
detract aesthetically from the environment. Maintenance and repair requirements can be extensive, and the expenses can grossly exceed the original cost of the foundation.

(2) *Occurrence of damages.* Damages can occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occurs to disturb the soil moisture. The probability of damages increases for structures on swelling foundation soils if the climate and other field environment, effects of construction, and effects of occupancy tend to promote moisture changes in the soil.

5 MECHANISM FOR MOISTURE INGRESS AND REMOVAL

Cyclical Water Ingress and Removal causes moisture imbalance that triggers the *"Shrink-Swell Cycles"*.

The cyclical nature of the *"shrink-swell cycle"* is caused by the periodic entry and evacuation of water in the soil. If only moisture equilibrium can be maintained within the structure then the damage due to cyclic movements of water into and out of the soil can be prevented or minimized. This points to one remediation measure that could be effective in remediating existing structures that have experienced damage due to swelling and shrinking of the soils.



The figure above taken from ***Ref. 4.0*** shows how water can find its way into and under a structure. In addition several other soil mechanisms and behavior tend to cause this cyclic movement of soils into and out of the structure footprint causing shrink swell cycles.

The following properties help us to understand the swell and shrink tendency of highly plastic soils:

- FINE GRAINED SOILS possess characteristic Crystal Lattices that are very small and could not normally be seen even under a Microscope.
- These Crystals possess electrical charges. The finer the crystals the greater is the surface area and the attractive electrical charges.
- The electrical attractive forces and the high affinity for water are very great as to cause separation of the clay platelets to adsorb the water and cations.
- This continued *adsorption* and *absorption* causes the swelling of the soil which could be reversible during periods of evapotraspiration and Matric suction.
- This phenomenon causes the shrink swell cycle.
- Salt Cations in the soil water are attracted to the surface of the Lattice crystals to balance the Charges.
- These salt cations such as magnesium, alumina, sodium, potassium are dissolved in the soil water and adsorbed on the clay surfaces as exchangeable cations.
- The hydration of these Cations can cause the attraction and accumulation of water between the clay particles.

Other Factors that Contribute to this are:

- Soil Plasticity
- Dry Density – the greater the density, the greater the expansive potential.
- Initial Moisture Content
- Moisture variation – if the moisture is balanced and there are no variations in moisture then the cycle is interrupted.

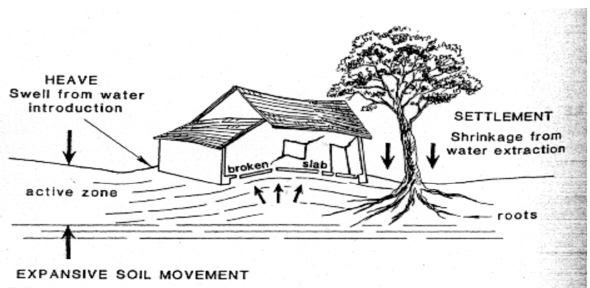


FIGURE 9.20 Illustration of center lift of the foundation.

The figure above shows how Moisture variation is caused by natural processes. In addition to this, water tend to move from hotter areas to cooler areas (such as under structures) in a process known as "*Thermal Migration*". Thus over a period of time water would be slowly injected underneath structures further aided by *Matric Suction.*

The moisture buildup does NOT necessarily coincide with periods of high rainfall or Moisture such as during flooding. This is because the fine grained nature of the expansive soils have very low permeability and thus we would sometimes find that swelling would occur *after* the rainy season or in a dry spell after considerable time from the exposure to inundation or saturation.

However, continued inundation or flooding of a surrounding area could cause heaving to occur after a period of time.

6 PATTERNS OF HEAVE

There are several patterns of heaving ***(Ref. 2.0)*** due to swelling soils that could occur or affect a structure depending on the Ground water regime or water infiltration and also the timing of construction:

6.1 Doming Heave

Heave can occur as an upward long term dome shaped movement that develops over many years.

6.2 Cycle Heave

A cyclic contraction – expansion related to drainage and the frequency and amount of rainfall and evaporation.

6.3 Edge Heave

This kind of heave may be observable soon after construction in preconstruction vegetation and lack of topographic relief. Removal of vegetation leads to an increase in soil moisture while flat topography leads to ponding.

6.4 Lateral Heave

Lateral thrust of expansive soil with a horizontal force approaching the passive earth pressure can cause bulging and fracture of basement walls and retaining walls.

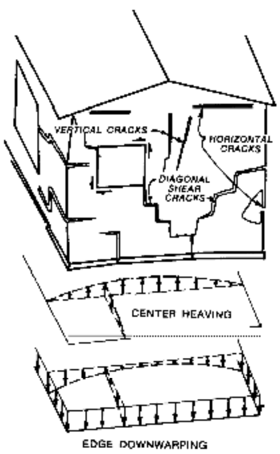
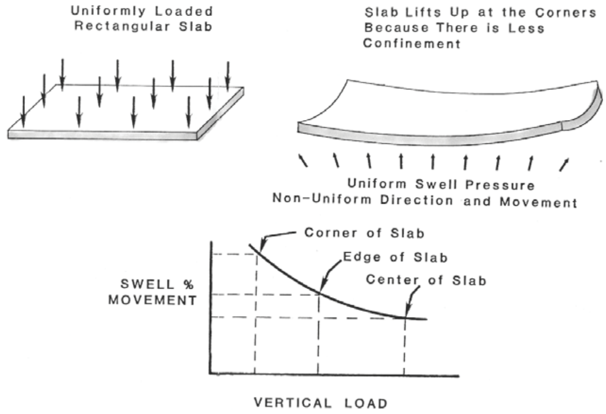


Figure 1-2. Examples of wall fractures from doming heave of swelling and shrinking foundation soils.



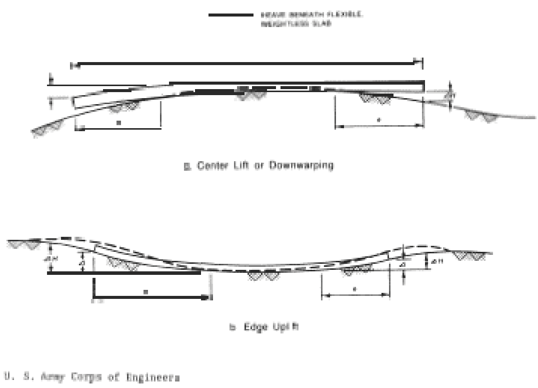


Figure 5-3. Soil slab displacements on heaving soil.

The figure above show cracking on light residential structures and deformations in lightly loaded roadway pavements due to center lift and edge uplift ***(Ref. 2.0).***

7 DETECTION AND IDENTIFICATION OF SHRINK SWELL TENDENCY

Detection of Swell tendency of soils is relatively simple and straightforward and normally relies on inexpensive laboratory tests that are part of the Soil Evaluation report. We refer specifically to the prevalence of SOIL INDEX TESTS such as the very well known "*Atterberg Limits Tests*" and grain size analyses to provide *initial* indication of expansive potential.

Oftentimes, more expensive tests may NOT even be needed during the early part such as the use of X-Ray Diffraction methods as well as Swell pressure tests. The *Atterberg Limits* are a *telltale* for expansive tendencies and numerous correlations with the Liquid Limit and the Plasticity Index as well as the Fine fractions (minus # 200 Sieve) have been published in literature to gage expansive potential of the soils.

But why are these tests NOT being used for this purpose? We believe that the reason is that Expansive potential is Not even recognized as a reality in a Tropical setting because most published literature about the subject always speak about occurrence of Expansive soils only in Arid Desert settings.

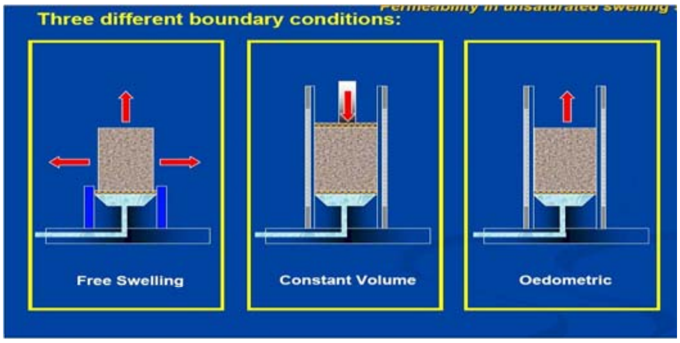
TABLE 3.4. Expansive soil classification based on percent passing no. 200 sieve, liquid limit, and standard penetration resistance for Rocky Mountain soils

Laboratory and Field Data				
Percentage Passing No. 200 Sieve	Liquid Limit (%)	Standard Penetration Resistance (Blows/ft)	Probable Expansion (% Total Volume Change)	Degree of Expansion
>95	>60	>30	>10	Very high
60–95	40–60	20–30	3–10	High
30–60	30–40	10–20	1–5	Medium
<30	<30	<10	<1	Low

After Chen (1965).

John D. Nelson & Debora J. Miller. Expansive Soils - Problems and Practice in Foundation and Pavement Engineering, p. 52

The figure below shows the various laboratory tests that could be undertaken to confirm the swell tendency of the soil by measurement of Volume change or Swell Pressure under confined conditions after the tendency has been initially identified.



A **B** **C**

Ref. 5.0

The Figure "A" shows the free swell test where the soil specimen is allowed to swell in all directions under unconfined conditions in order to measure the magnitude of swelling that could occur under unrestrained conditions.

The test (Second Figure "B") is to determine the swell pressure of a compacted specimen of soil under ZERO Volume Change or the constant Volume test. The Soil is saturated under the prescribed overburden and allowed to swell under lateral confinement. The heave is registered and the load is increased to return the soil to Zero Heave. The cycle is repeated until no further heaving is observed. The resulting load to return it to zero swell is the swell pressure.

In the Oedometer (Third Figure "C") Swell Test, the Undisturbed or Compacted Specimen is Saturated and allowed to swell under increasing Load as in the regular consolidation Test. The amount of Swell is recorded as a % of the Specimen Height.

8 OUTLINE OF RESPONSE STRATEGIES BEFORE CONSTRUCTION

It would be far easier to avoid the problem brought about by swelling soils if this is *recognized* **before** construction is started rather than to undertake remediation when the problem has manifested itself. Thus a careful study of the area would be required in order to determine whether swelling would be a problem. This could be done by conducting simple reconnaissance of the surrounding areas to see whether cracking is manifested in the roadway pavements, fences and even the houses and by interviewing owners of adjacent properties. In addition, inexpensive soil index tests can be performed on suspect soils to determine whether the soil indices (LL & PI) as well as the Fine fractions (minus #200 Sieve) indicate swell potential or not.

The following are some of the response strategies that could be resorted to before construction, once the target site exhibits soils with swell tendency:

- Removal of problem soils before construction

  Typically, expansive soils have relatively shallow occurrences (to within 2.0 to 4.0 meters from the natural ground line (NGL) as the expansive alumina is concentrated by shallow leaching of the soils. However, there are also extensive deposits that are significantly thick and this would have to be ascertained. If the expansive soils are relatively thin, then removal would be the best solution to totally eliminate the problem. In case this is not possible, other solutions can be resorted to.

- Elimination of source of water

  Water triggers the expansion of swelling soils. The volume change is due to progressive adsorption and absorption of water. If water can be eliminated *Totally* (which would be at best difficult) then the problem is arrested. There is no clear cut and foolproof way of totally eliminating water under structures because of the infiltration of water from seasonal rainfall, from leakages in the domestic water system as well as the sewer system and due to Thermal Migration. Thus, this solution is **NOT** totally effective.

- Maintainance of moisture equilibrium

  The Shrink Swell cycle occurs due to seasonal or cyclic changes in water content. If the Moisture equilibrium can be maintained, then the initial swell that has occurred will no longer progress and shrinkage is prevented by preventing exit of the water underneath the structure. The key is to preserve the moisture balance as a way to avoiding progressive and periodic volume changes. This is done by providing impermeable vertical barriers (HDPE or GCL) sufficiently deep to prevent moisture migration both ways.

  The vertical Moisture barrier in the figure below can be any durable *impermeable* liner such as HDPE or Geosynthetic Clay Liner or plastic walls (Cement Bentonite liner).

HDPE Barrier Walls has been used successfully by the authors in several projects.

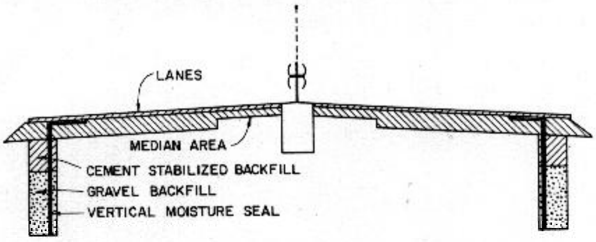


FIGURE 5.24. Deep vertical moisture barriers used on a San Antonio freeway.

- Reduction of soil compaction and compacting wet of OMC (Prewetting).

  Surprisingly, reduction of compaction density could reduce the total swell magnitude. This is done by compacting the soil wet of optimum and by prewetting. The resulting lowered soil density will reduce the rebound swell magnitude in much the same way that a coiled spring will rebound less if the precompression is reduced.

  However, controlling the migration of moisture complicates this solution and therefore the latter has to also be addressed in conjunction with this solution.

- Chemical treatment with quicklime, Portland Cement or other stabilizing agents.

  The liquid Limit and the Plasticity Index of expansive soils stabilized with quicklime abruptly decreases which also indicates that the swell potential is significantly reduced. The quicklime chemically reacts with the soils and reduces the activity of the soil as well as providing bonding of the soil particles as to reduce the swell potential. Stabilization by quicklime also increased the overall strength of the stabilized soil.

  Other chemical stabilizing agents are also available that could act on the expansive soils but these should be tested in the laboratory before being used in the problem.

- Structural Responses

  Structural responses are resorted to if the other procedures are impractical or not feasible. These are discussed in more detail in subsequent sections and should be used as a last resort to gage effectiveness.

- Countering the Swell Pressure Magnitude by Increasing the Intensity of Dead Load Contact Pressure

  The contact pressure from the *dead load* is increased by reducing the footing contact area as shown diagrammatically below. The swell pressure has to be measured in the laboratory using the confined swell test or constant volume test to determine the maximum potential swell pressure that could be generated, simulating the actual density of the soil in-situ.

  Thus, if the structural clement is heavier or larger than the swell pressure, no heaving would result.

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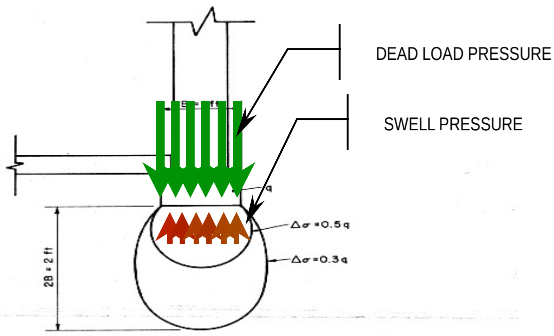

FIGURE 5.23. Pressure bulb below narrow footing.

TM 5-818-7

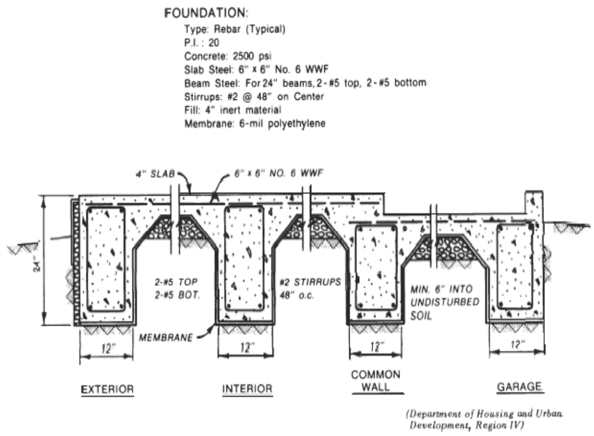

Figure 6-5. Typical conventional rebar slab in Little Rock, Arkansas, for single-family, single-story, minimally loaded frame residence with 11- to 12-foot wall spacing.

The figure above ***(Ref. 2.0)*** illustrates the common procedure in increasing the deadweight contact pressure of the structure while at the same time making the slab stiffer. The Stiffened slab and Beam construction is designed to resist the swell pressure and the weigh of the structure is supported only as Line loads. Thus the deadweight effectively counteracts the Swell pressure.

A variation of this construction is by use of Post tensioned slab to further increase the stiffness.

Another defensive construction uses walls without footings or footings with large gaps or voids to increase the contact pressure.

The Wall becomes the Bearing element without any footing to increase the counterweight or with a reduced footing

Contact area with Void Spaces to relieve the swell Pressure and Funnel it into the Voids.

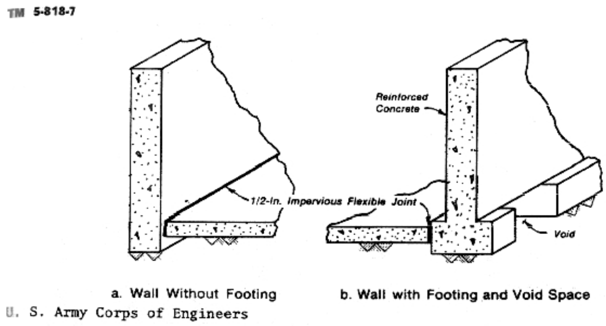

Figure 6-4. Basement walls with slab-on-grade.

- Use of Piling

  The use of piling to bypass the swelling soils and resist the swell uplift by anchoring the piles sufficiently or even with the use of belled bottoms is resorted to in extreme cases. The Floors are all structurally suspended on the piles so as not to be affected by the swell pressure.

  The figure below illustrates the procedure: ***(Ref. 2.0)***

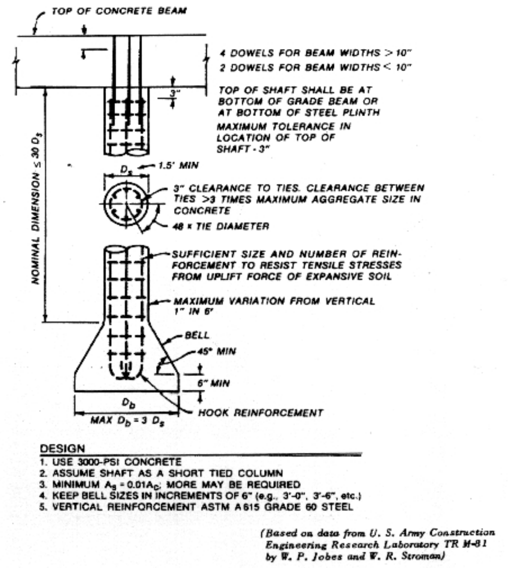

Figure 6-10. Drilled shaft details.

  The piles are often belled to increase the resistance against uplift.

- Release of Floor slab

  The floor slab is freed from any restraint and is removed from any contact with the swelling soil or the slab is totally free to move or "*Float*" with the swelling soil when heaving occurs.

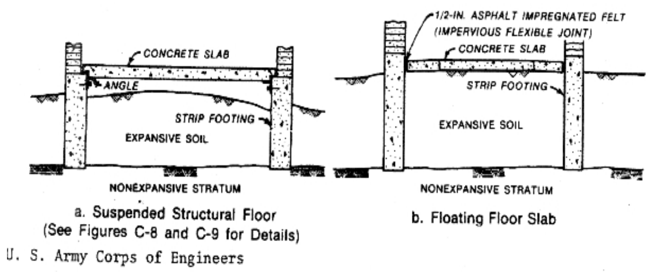

Figure 6-2. Footings on nonexpansive stratum.

9 RESPONSE AND REMEDIATION STRATEGIES FOR RESIDENTIAL BUILDING CONSTRUCTION

- Swelling soils cause damage to thousands of homes every year.

  The extent of the damage varies from cracked driveways and sidewalks to severe structural deformation.

  Even well designed and constructed homes can be damaged if proper landscape installation and maintenance practices are not followed some precautions are necessary:

- Don't allow sprinkler systems to spray any closer than five feet from the foundation. And plant trees no closer than fifteen feet from the foundation.

- It's also important to carefully regulate water applied near the foundation. And avoid the temptation to remove downspout extensions to harvest water for flower beds near the house.

Also, avoid unlined plantboxes.

10 SUMMARY AND CONCLUSIONS

- Potentially Swelling soils are Prevalent in our Country and must be recognized as a real problem.

- The Reduction or Prevention of Damage is Relatively Easy and inexpensive if detected early before Construction through the conduct of simple Soil Laboratory Index Tests.

- Once detected, the problem can be eliminated early on by removal as the swelling soils are relatively shallow in occurrence.

- Remediation and repair of damage caused by swelling soils on the other hand is relatively very costly, difficult and disruptive and can be prevented if careful steps as above are taken before construction.

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Note:

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