EFFECTS OF TREES ON THE DEPTH OF THE ACTIVE ZONE

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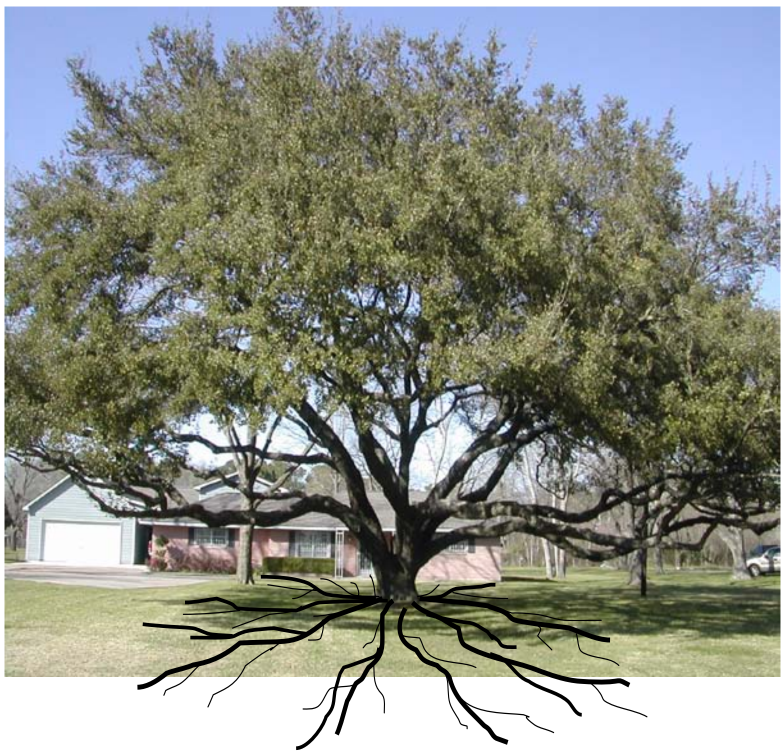
Expansive clays in the active zone can cause major damages to foundations, structures, pipelines and other civil infrastructures that are supported on it due to fluctuations in moisture content. Moisture demand of trees can significantly impact the depth of the active zone.



ACTIVE ZONE

O'Neill (1980) reported that the depth of the active zone is 5 to 10 feet in Houston, Texas. The active depth was determined by plotting liquidity index with depth using data from geotechnical investigation reports at sites without trees. Geotechnical engineers now refer to this zone as the "depth of seasonal moisture change".

Nelson (2001) classifies the active zone as the zone where moisture changes are presently occurring which can be distinctly different than the depth of "seasonal moisture change". He defines the maximum depth of the active zone as to where the overburden pressure equals the zero swell pressure.

O'Neill was aware of the effects of trees and stated in his paper "shallow root systems continuously remove moisture from near surface soil and desiccate expansive clays". Tand

(2008) reported that the depth of moisture variation can be deeper than 20 feet. Historically, the typical bearing depth of underreamed piers in the Houston area has been 10 ± 2 feet. This will situate the piers within the active zone at sites where large trees or clusters of trees had been removed shortly before construction, or at sites where existing or newly planted trees are located close to buildings.

CASE 1 (Heave of Foundation)

The site is located in the greater Bellaire area in Houston, Texas. Two steel frame building were constructed in the early 2000s. The foundation system was underreamed piers bearing at a depth of 10½ feet below top of slab.

Pre-construction vegetation consisted of grass with scattered large oak and other hardwood trees. Fifteen trees had to be removed from under the two building footprints, and there were five additional trees close to the buildings that had to be removed.

The floor slabs are situated on ±3½ feet of sandy clay fill with a low to moderate shrink/swell potential (PI ±20). The fill is underlain by about 12 feet of clay with a high to very high shrink/swell potential (PI ±60). The clay is underlain by a thick strata of sandy clay with a low to moderate shrink/swell potential (PI ±15). No groundwater was encountered when drilling the pre-construction borings.

The pre-construction potential vertical rise (PVR) computed using Tex 124-E was reported as ±1 inch with the floor slab on 3½ feet of select fill. Foundation movements were first noted about 3 years after completion of the buildings. Elevation surveys indicate that the east building's ground floor slab heaved ±3 inches, and that the west building's ground floor slab heaved ±5 inches. Elevations of the floor slab near the columns on the 2nd floor suggest that swell of the clays below the underreamed piers heaved them up ±1½ inches. Other possible explanations include: (1) tension failure occurred at the shaft/grade beam interface allowing the columns that are supported on the grade beams to move up independent of the piers, (2) the shafts were pulled apart due to tension, or (3) pullout of the piers occurred due to soil failure above the underreams.

Subsoil data from a nearby site without trees indicates that the depth of the water table was ±15 feet in the early 1970s. Moisture demand of the trees at this site had caused the groundwater level to be lowered below 25 feet. Post-construction borings indicate that the water level rebounded to a depth of 17 feet within a period of about 6 years. This resulted in a bottom to top wetting front. In addition, there is an upper water table at a depth of about 4 feet suggesting that there was moisture migration from landscape areas around the buildings to under the slabs through sand backfill around sewer pipes, voids under the grade beams, and possibly leaking underground sewers.

The pre-construction depth of the active zone was estimated to be 7 feet. Shown on Figure 1 is a graph of moisture content/depth comparing the pre-construction versus post-construction laboratory data that indicates the depth of moisture change was greater than 25 feet. An average Tex 124-E moisture condition was assumed for start of swell. However, post-construction analysis suggests that the moisture condition was dry at the start of earthwork construction. The measured heave was 3 to 5 times greater than the initially reported PVR of ±1 inch because the effects of the trees had not been understood.

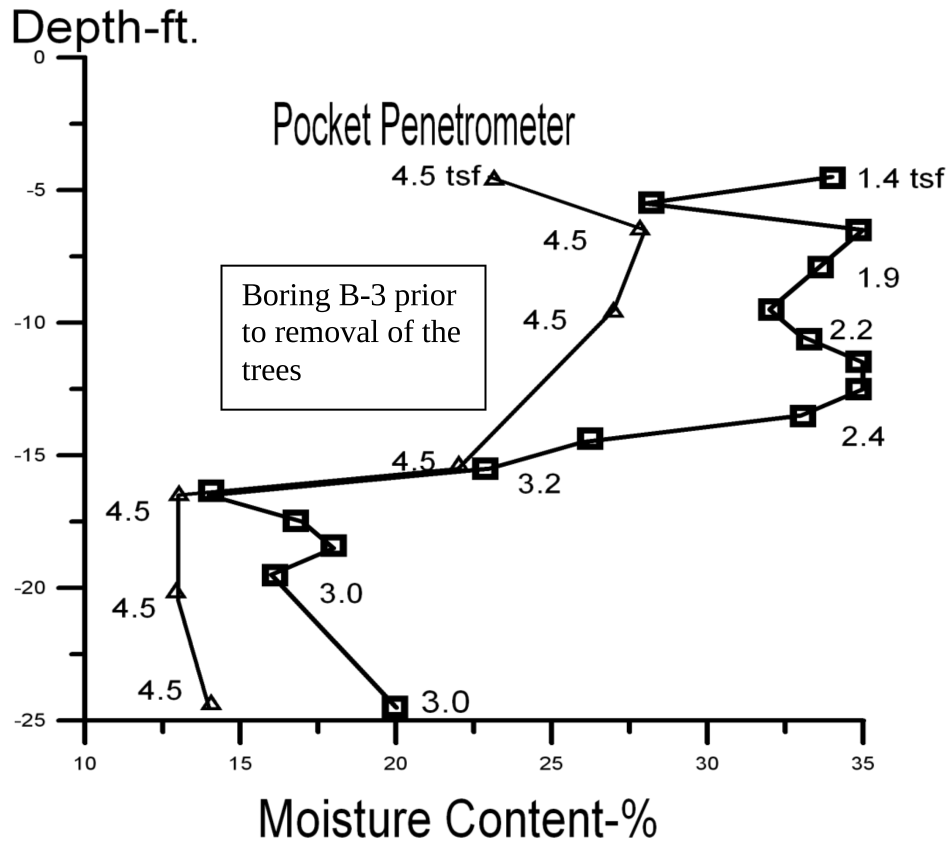


Figure 1: Variation of Moisture Content and Preconsolidation Pressure with Depth for CASE 1

CASE 2 (Settlement of Foundation)

Case 2 is at a site southeast of the Texas Medical Center in Houston. The building (now demolished) was a 2-story steel frame structure constructed in 1970. The structural plans indicate that the foundation system was underreamed piers bearing at a depth of about 17 feet below top of slab (±13 feet below natural grade).

The floor slab was elevated on ±4 feet of sandy clay fill with a moderate shrink/swell potential (PI ±23). The fill was underlain by about 18 feet of clay with a high to very high shrink/swell potential (PI±65). A layer of water bearing, very silty clay was encountered below the clay.

The elevation survey indicated that ±3¼ inches of settlement of the floor slab occurred at the SE corner. There was a 5½ inch void under the slab indicating that the ground surface below the slab had settled ±8½ inches. About 1 inch of settlement occurred in the NE corner, and there was a 3¾ inch void under the floor slab. This indicates that the ground surface below the slab settled ±5 inches.

Elevation of the floor slab on the 2nd level at the SE corner suggests that the underreamed pier settled ±3 inches. This underreamed pier was probed and found to be bearing at a depth of 14½ feet below top of slab. The underreamed pier at the NE corner settled ±1¼ inches. This pier was also probed and found to be bearing at a depth of 16½ feet below top of slab.

Two 20 to 32 inch diameter oak trees were located near the SE corner, and the drip line was within 6 feet of the perimeter. Abundant feeder roots were found in the upper 10 feet, with occasional feeder roots found between 10 and 15 feet. One 1/32 inch diameter live root was found at a depth of 19 feet. One large ash tree and a small oak tree were located near the NE corner. The drip line of the ash tree was at the perimeter of the building.

Shown on Figure 2 is a graph of moisture content/depth comparing the moisture content variation with depth at a boring near the SE corner of the building close to the trees, and at a boring well beyond the trees. The subsoil data indicates that the depth of moisture variation was about 20 feet below grade. The layer of water bearing silty clay at 22 feet was permeable enough to replenish moisture at the 20 foot depth as water was being sucked out due to moisture demand of the trees.

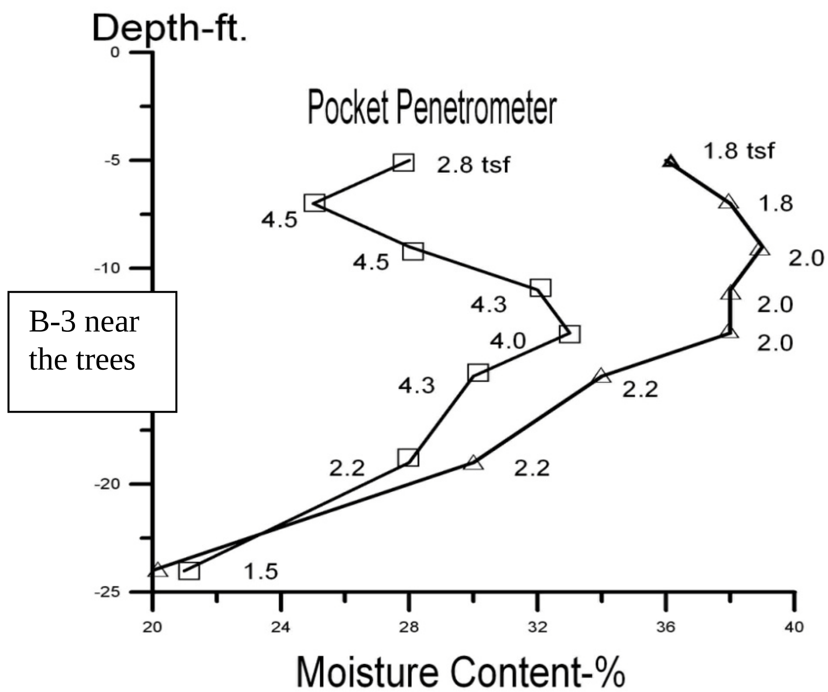


Figure 2: Variation of Moisture Content and Preconsolidation Pressure with Depth for CASE 2

LESSONS LEARNED

- Moisture demand from trees on expansive clay can increase the depth of the "seasonal active zone" in Houston from 5 to 10 feet (O'Neill) to 20 feet or deeper.
- Deep underreamed piers or drilled piles will be required to situate the piers/piles in a stable zone below the active depth at locations where moderate to large trees and clusters of trees are removed. The piers/piles will have to be placed a sufficient depth below the active zone to resist pullout, and they will have to be reinforced to resist the tension forces induced by swelling of the clays. A structurally suspended floor slab with voids under the grade beams will be required. This also applies to sites with existing trees close to the perimeter as there is no guarantee that the trees will not die or be removed at a later date.
- Deep underreamed piers or drilled piles will also be required to situate them below the active zone in areas where new trees are planted within a zone that will result in desiccation of the clays below buildings. The floor slab will have to be structurally designed for loss of ground support.
- The subsoil conditions, presence of existing and proposed vegetation, and structural loading conditions will vary at each site. Thus, there are no absolute rules that will apply for design of foundations. Each site should be analyzed by a competent geotechnical engineer for its' specific design requirements.
- Only a landscape architect experienced in planting vegetation and trees in areas with expansive clay should be employed to design the landscaping.

O'Neill, M. W. and Poormoayed, N. (1980) "Methodology for Foundations on Expansive Soils", *J. Geotechnical Engineering Division*, *ASCE 106*, *G T 12*, December, pp. 1345-1367.

Nelson, J., Overton, D., and Durkee, D. (2001). "Depth of Wetting and the Active Zone", Expansive Clay Soils and Vegetative Influence on Shallow Foundations, *ASCE Geotechnical Special Publication* No. 115, pp. 95-109.

Tand, K.E. (2008) "Settlement of Foundations on Expansive Clays", 2008 CIGMAT Conference, Houston, Texas