EFFECT OF ENVIRONMENTAL CHANGES ON DEPTH OF THE ACTIVE ZONE

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Abstract

The active zone is defined as either the depth of seasonal movement or the depth to which changes in soil moisture or suction will cause movement. It is critical in the analysis of expansive soils to accurately define the depth of the active zone to estimate the potential for movement.

The depth of the active zone will vary with changes in environmental conditions. Examples of changes in environmental conditions include the normal variation in rainfall, but also modification of surface grades which affect runoff coefficients, installation of irrigation, modification of prevailing plant species, and stress changes associated with cut and fill. All of these factors are included in a typical development project.

Various publications define the depth of the active zone as the depth at which either constant moisture or suction is observed. This depth is only relevant for the prevailing environmental conditions at the time of sampling. Inevitable changes as a result of development must be accounted for to properly predict the active depth and subsequent potential for movement.

Introduction

To predict potential movement associated with either expansive- or shrinkage-prone clay profiles, an adequate definition of the depth of the zone of activity is required. If the depth of the zone is under-predicted, then more movement than anticipated can occur. This has both performance issues for the structure and legal implications for the design team.

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The purpose of this paper is to present various definitions in the literature of the active zone and propose a standard. It should be mentioned that this paper addresses the potential zone of activity, not the probable zone. In other words, the definition proposed for the active zone is relative to the full potential, not necessarily evaluation of the probable amount of movement.

Activity in clay profiles is associated with both heave and shrinkage. It is therefore proposed that the definition of the active zone be subdivided into a seasonal zone and a deeper "potentially" active zone.

A case study of the moisture changes within the deeper zone of activity over a 28-year period is provided. Differential heave of over 16 inches associated with an increase in moisture to a depth in excess of 25 feet was observed.

Shrinkage-prone profiles include locations where softer clays are subject to seasonal changes in soil moisture. The lower limit of drying may be associated with either shallow non-expansive materials (in North Texas, typically shallow rock) or shallow ground water.

Heave-prone profiles generally consist of deep, dry, residual clay, frequently severely weathered shale, that is not subject to seasonal moisture changes. Typical formations in North Texas include the Taylor Marl, Eagle Ford Group, Denton Clay and Kiamichi Formation. Severely weathered shale in these formations can remain relatively dry because of site topographic conditions allowing rapid runoff of surface water. Extensive growth of trees, especially mesquite, can also cause significant drying to depths well below any seasonal activity.

This paper does not address the various methods for defining the magnitude of movement, or defining the potential swell pressure. This subject is left for future discussion.

Definitions of Active Zone

Various definitions can be found within the literature regarding the active zone. One of the earlier papers on expansive soils was written in 1956 by Holtz and Gibbs.

The active zone is not specifically named; however, the depth of activity was implied in their discussion of the design for the Welton-Mohawk Pumping Plants. The design depth was taken to equal 20 feet, since at this depth the structural loads plus overburden pressure was sufficient to restrain swell.

Chen (1988) defined the active zone as "the thickness of the layer of soil in which a moisture deficiency exists." Chen further states that the "depth of the active zone is generally greater than the depth of seasonal moisture variation."

Consistent with Chen, Reed (1985) proposed dividing the active zone into two sub-zones; a seasonally-active portion, and a zone of "deep-seated" movement. The latter was defined as the portion of the active zone where the potential swell pressures exceed the overburden stress.

Fredlund and Rahardjo (1993) define the "active zone" as the "zone of soil undergoing volume change on an annual basis". Inherent in this definition is the concept of a seasonally-active soil.

More recently, Nelson, Overton and Durkee (2001) proposed that the active zone be defined as "that zone of soil that is contributing to heave due to soil expansion at any particular time." The depth of the active zone is further defined as "the depth to which the overburden vertical stress equals or exceeds the swelling pressure of the soil".

Lu and Likos (2004) define the active zone as the portion of the soil profile which is subject to time-dependent environmental factors which cause the soil suction near the ground surface to fluctuate. This definition implies that the active zone would be "near the ground surface".

The Third Edition of the PTI Manual (2004) defines the active zone as the "depth of soil suction variation". Implied within this definition is the concept that any change in the soil suction would result in volume change. However, the manual goes on to state that the recommended soil design values are based on soil moisture being controlled by climate alone. This implies a seasonally-active zone.

It is the definition Nelson, Overton and Durkee propose that the writer recommends be adopted for routine investigations. The full potential for movement can then be addressed, followed with a subjective discussion of the probable movement. Using this concept would allow the client and/or design team to make decisions relative to the risks associated with soil movement versus costs to mitigate the risk.

Evaluation of Seasonal Moisture Fluctuation

This zone is defined almost universally as the zone of soil in which water contents change due to climatic changes at the ground surface.

This concept is relatively easy to grasp; however, it should be emphasized that the seasonal climatic conditions can change significantly between various years. One measure of the changes in the yearly variation is the Thornthwaite Index (1948). An example of the yearly variation in the Thornthwaite Index for the Dallas area is provided in Figure 1.

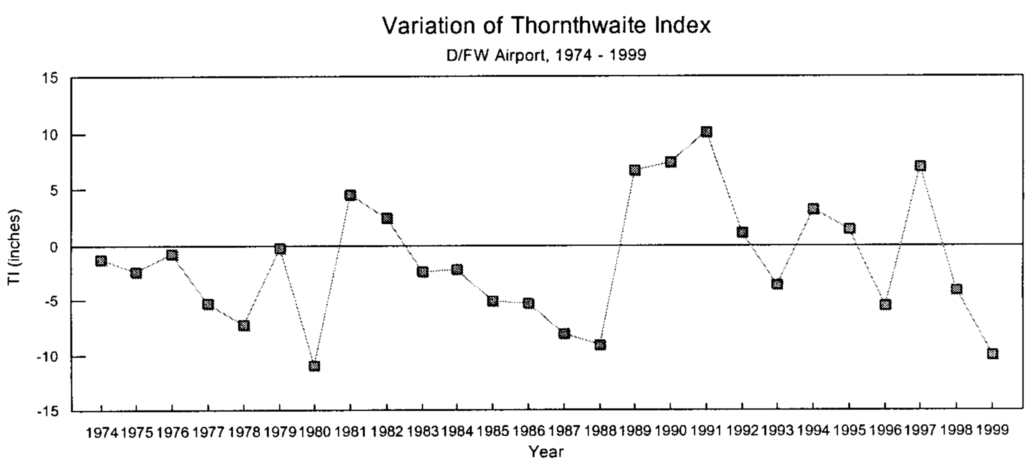

Figure 1. Yearly Variation in Thornthwaite Index.

Analysis of Figure 1 clearly illustrates that the depth of seasonal drying would not be a constant. It is anticipated that seasonal drying would be significantly different in 1980 relative to 1991. It is also probable that any design assumptions based on an average of the yearly Thornthwaite Index would over-predict movement in wet years and under-predict movement in dry years. This concept is consistent with findings by McKeen and Johnson (1990) who concluded that an estimate of seasonal changes must account for the variation in yearly climate over the design life.

The depth of seasonal activity will also vary with changes in site grades. Sites with grass-covered clay slopes of over 8% have a runoff coefficient of 0.26 to 0.36. Sites with grass-covered clay slopes of less than 2% have runoff coefficient of 0.10 to 0.16. The lower runoff coefficient reflects the potential for an increase in surface infiltration and a slower rate of movement. If the geotechnical investigation is performed prior to site grading and the depth of seasonal activity is taken to equal the depth at which a constant moisture or suction is obtained, significant variation may occur once the site is graded.

Obviously, changes in the seasonal zone would be affected by changes in grade. Significant grading can remove the entire zone of seasonal activity. Soils below the seasonal zone would be expected to have different vertical to horizontal stress conditions; hence different swell characteristics.

Similar arguments can be made for the changes in the seasonal zone associated with the addition of irrigation. The addition of irrigation effectively increases the average Thornthwaite Index. Within the North Texas area, an average of 20 inches of irrigation is added to the soil profile during the growing season.

Evaluation of the Depth of Activity

In accordance with Nelson, Overton and Durkee (2001), the zone of activity can be defined as the depth at which the overburden pressure exceeds the available swell pressure.

Various arguments can be made regarding the potential swell pressure, but that discussion is beyond the scope of this paper.

It can also be argued that the wetting front cannot or will not migrate to great depths because of permeability. This argument could be used to evaluate the probability of movement, i.e., although a potential for movement may exist, the probability of the movement occurring is limited because of low permeability. Again, this portion of the discussion is beyond the scope of this paper.

Rather than argue the theoretical concepts of swell pressure and permeability, a case study is offered to illustrate the concept that heave can occur well below the zone of seasonal activity.

The case study consists of observation of the magnitude of heave over a 28-year period. The structure consists of a tilt-wall office/warehouse constructed within residual soils of the Eagle Ford Group. The site is located within Irving, Texas which is situated in an area with an average Thornthwaite Index of 0. Subsurface conditions consist of one to three feet of reworked on-site soils over severely weathered shale. The severely weathered shale extended to depths in excess of 40 feet.

Foundation support for the structure was provided by underreamed piers founded at a depth of 15 feet below finished floor. The floor is a ground-supported "floating" slab over three feet of clayey sand [Plasticity Index (PI) of 10 to 15]. Site grade required an estimated six to eight feet of excavation on the western end of the site and an approximate equal fill on the eastern end.

The pre-construction geotechnical investigation was preformed in 1977. The most recent investigation was performed in 2005.

A relative differential elevation survey of the floor was performed in 2005. A copy of the elevation survey is provided in Figure 2.

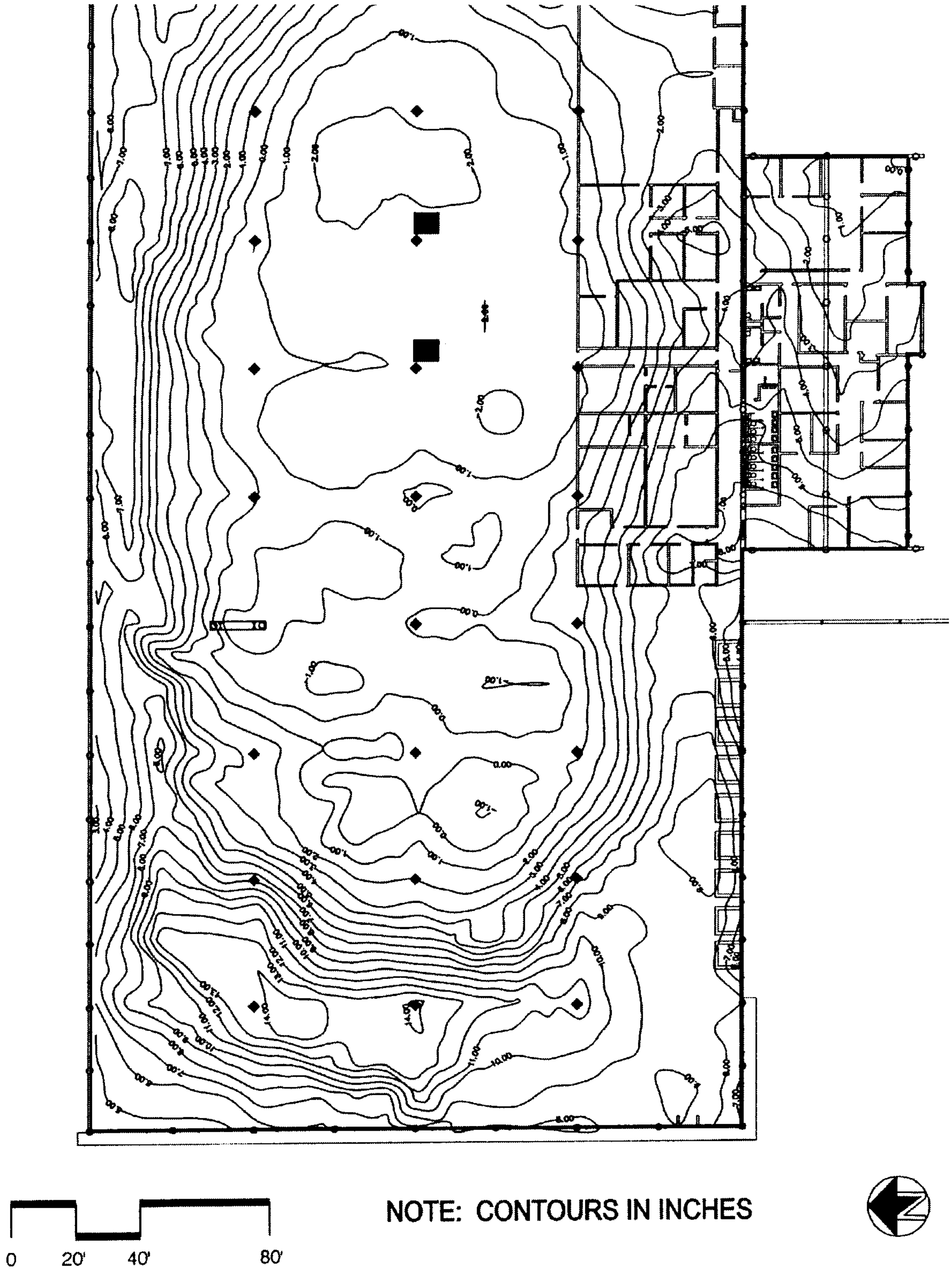

Figure 2. Relative differential elevation survey of site in Irving, Texas.

Based on the survey, the maximum differential elevation from the high to the low point of the floor slab was on the order of 16 inches, measured from the center of the warehouse slab to the high point at the west end of the building. The pattern of movement is consistent with the wetting front moving from the building exterior to the interior. The pattern of movement is not consistent with the presence of natural ground water.

The pattern indicated by the elevation survey is also consistent with some differential movement of the piers supporting the tilt-wall panels. Based on the observed pattern of movement, it is estimated that the underreamed piers have moved two to seven inches differentially since construction, dependent upon location. It appears the area of greatest pier movement is at the west end of the building. Movement is attributed to heave of the severely weathered shale below the founding depth of the piers.

As the severely weathered shale heaves, there would be a corresponding increase in the soil moisture. A comparison of the moisture contents of the severely weathered shale, prior to construction of the building in 1977 and during recent field operations (2005) at the northwest corner of the building, is presented in Figure 3. The comparison shown in Figure 3 indicates a significant increase in moisture within the severely weathered shale during the life of the structure.

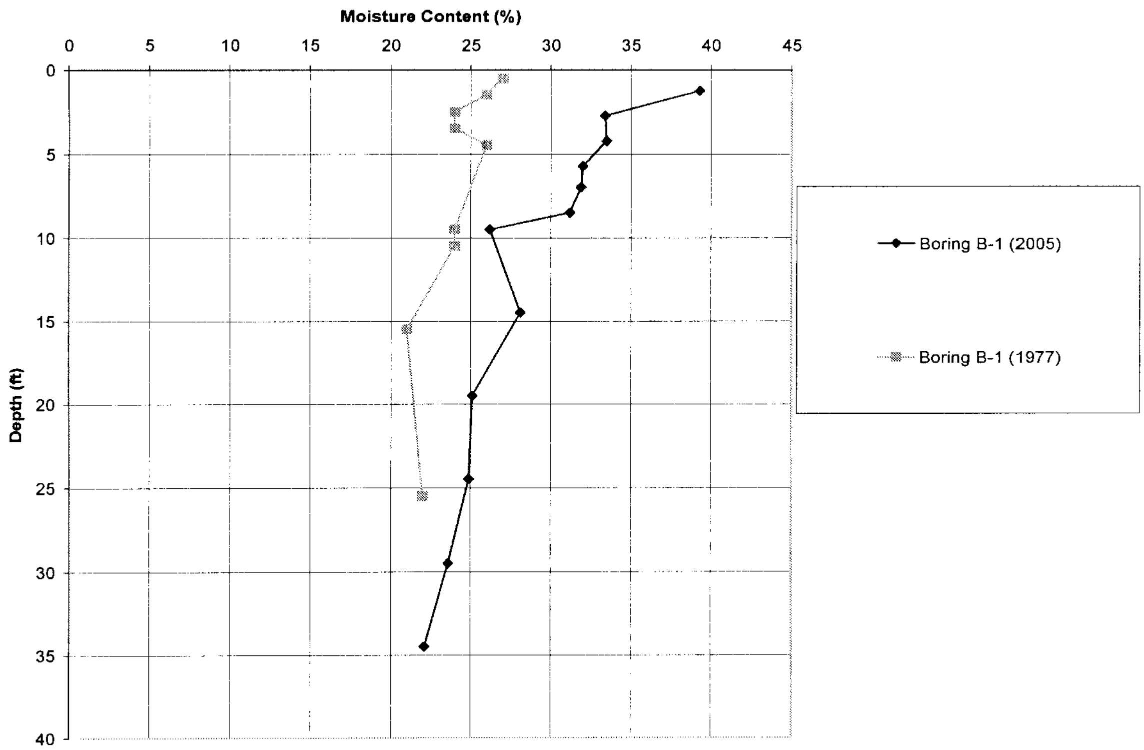

Figure 3. Moisture Content Profile - Northwest Corner of Building.

A comparison of the two moisture content profiles in Figure 3 indicates a significant increase in moisture since project construction. Local experience in the Eagle Ford Group indicates an approximate one percent vertical swell for each one percent gain in moisture. Using this correlation and the two moisture profiles shown in Figure 3, discounting the upper 1-1/2 feet, an estimate of heave of 17-3/4 inches is obtained. This correlation would indicate that approximately 10-1/2 inches of heave would be anticipated within the upper 15 feet, with a balance of approximately 7-1/4 inches of heave occurring below a depth of 15 feet. Considering the relative accuracy of the available information, the correlation between moisture gain and observed differential elevation of both the floor and tilt-wall panels is reasonable.

It is realized that the case study is likely an extreme case. However, an analysis of the change in moisture should result in an acceptance of the concept of the potential for heave occurring below the seasonal zone.

Conclusions

A consistent definition of the zone of activity is presented for use in general practice. In accordance with Nelson, Overton and Durkee (2001), the definition the active zone consists of "the depth to which the overburden vertical stress equals or exceeds the swelling pressure of the soil".

Although the potential for movement at depth may exist, the probability of the movement may be undefined. By understanding the difference between potential versus probable movement, the geotechnical engineering community may be able to qualify the unknowns associated with estimated movement relative to building and/or foundation performance.

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