ALTERNATIVE EARTHWORK PROCEDURE FOR EXPANSIVE SOILS

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Abstract

A wide variation in geologic conditions within the North Texas region allows for numerous methods to reduce the potential movement of a ground-supported floor slab constructed over expansive soils. Methods commonly used include isolation, removal and replacement of the expansive soils with inert fill, and preswelling via either mechanical excavation or high-pressure water injection. The preswelled soils are then capped to limit post-construction drying and to increase the subgrade modulus.

A brief description of each of the processes used to deal with expansive soils is provided. Specific emphasis is given to the use of the high-pressure water injection process to preswell soils. Typical moisture and suction profiles for varying geologic conditions are provided for background information.

An alternative procedure, designated the "picture frame method", consists of construction of an earthen, preswelled "dam" around the building perimeter to isolate the interior portion of the structure from moisture change. Analysis using antidotal information from observation of building performance was utilized to evaluate the width of the required dam. An 18-meter width was used for the case history. The depth varies with the geologic setting. A case history for a 59,130-square meter (sq.m.) office/warehouse is provided.

Introduction

Expansive soils present varying challenges to the design and construction of floor slabs in large industrial structures. The design is typically constrained by both use (such as heavy loads or super flat conditions), and by cost. The design must be functional for the intended use; however, excessively expensive designs are also unacceptable.

The purpose of this paper is to describe an alternative earthwork procedure to minimize the potential for movement below large industrial floor slabs. The procedure, designated the "picture frame method", consists of treating the perimeter zone subject to moisture changes while isolating the potential for moisture change within the building interior.

General background, design procedure and case history are presented in the following sections.

Geologic Setting

The north Texas area consists of a wide variation in geologic conditions. Within just the Dallas and Fort Worth area, there are 15 Cretaceous geologic formations overlain with varying thicknesses of Pleistocene and Holocene deposits. The Cretaceous formations vary from soft to hard limestone with interbedded soft shale to relatively massive formations of soft shale. The limestone generally weathers to hard calcareous clay of moderate to high plasticity. The shale generally weathers to form highly plastic clay (dual classified as severely weathered shale).

The variation in geologic formations results in a multiple of conditions relative to expansive soils. The seasonal depth of activity can extend the full depth of shallower soil profiles, or to depths of 5.5 meters or greater during drought years where the soil profile extends below seasonal drying.

The potential for "deep-seated heave", defined as movement originating from profiles below seasonal moisture variations but where the swell pressure exceeds overburden pressure, can extend to depths of greater than 7.5 meters. The highly plastic clay derived from the shale formations frequently result in profiles of this nature.

Potential Vertical Movements

The potential vertical movements associated with the expansive soils vary with the geologic formation and soil profile. Movements of 5 to 7.5 centimeters are common in profiles where the clay is less than about 1.5 meters thick. Deeper soil profiles can result in seasonal movement of 10 to 15 centimeters.

Movement associated with "deep-seated heave" in the deeper soil profiles weathered from the shale are frequently measured to be 10 to 25 centimeters. The largest documented movement by the author is approximately 40 centimeters. Because of the pattern of movement and its relevance to the picture frame method, a survey of this structure is included in this paper.

Typical Design Procedures

Typical design procedures within expansive soils can be divided into two general categories; isolation, and ground-supported. Isolation involves construction of piers below the active zone, then suspension of the structure. A suspended floor is feasible for many structures; however, it is generally not acceptable for large industrial buildings because of both cost and load considerations.

An alternative to a suspended floor consists of isolation of the structure on piers and use of a ground-supported or "floating" slab. Various methods are used to reduce the potential for movement of a ground-supported slab. The methods can be grossly divided into "dry" and "wet" approaches. Under dry philosophy, the expansive soils are totally or partially excavated and replaced with an inert or non-expansive soil. The main problem with this approach in the Dallas/Fort Worth area has been the potential for movement of the expansive soils below the inert fill.

The wet approach typically consists of preswelling the upper expansive soils then placement of a cap to limit moisture loss prior to placement of the floor. The type of cap is also generally dictated by the desired subgrade modulus.

Two alternative methods are presently used to preswell the upper clay; mechanical excavation and re-compaction and use of multiple passes of water pressure injection. Mechanical excavation and re-compaction consists of excavation, mixing the expansive soils to above optimum moisture, then compaction at a controlled moisture and density. Typical specifications require compaction at +1 to +5 percentage points above ASTM D-698 optimum moisture, at a density of between 92 and 98 percent of maximum density.

The pressure injection alternative is somewhat unique to the Texas market. This procedure involves mechanically forcing rods into the ground then injection of water under high pressure to mechanically fracture the soil. Water in the fractures is then absorbed by the clay. Multiple passes of water injection are then performed for both lateral and vertical coverage.

The rods are typically spaced at approximate 1.5-meter intervals and are forced into the ground at approximate 0.3 to 0.45 meter between injections. Each pass is offset approximately 0.75 meter orthogonally from the previous pass. The typical depth of injection has historically been 2.5 to 3 meters; however, recent improvements in the available pressures have allowed successful injection to depths of 9 meters. A photograph of a typical injection rig is provided on Figure 1.

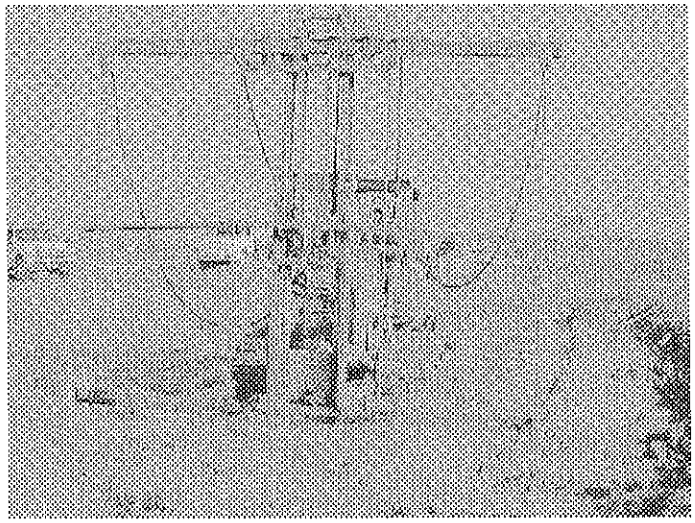

Figure 1. Typical water injection rig used in DFW area.

The alternatives discussed above are effective in reducing post-construction movement to a ground-supported slab when applied in the appropriate geologic setting. However, for large industrial structures greater than approximately 40,000 square meters, each of these procedures can be cost- and/or time-prohibitive.

Observation of ground-supported industrial office/warehouse floors within the Dallas/Fort Worth area that are not performing to an acceptable level typically finds differential movement along the building perimeter. Movement is attributed to moisture-induced heave and/or vegetation-induced drying and settlement. Instances of movement associated with a change in the ground water level have occurred. This type of movement is limited to specific geologic environments and is not addressed in this paper.

Limiting vegetation-induced drying and settlement is addressed by landscape design and/or root barriers. Moisture-induced heave, on the other hand, is associated with migration of a wetting front from the building perimeter into the drier soils in the interior of the structure. Preswelling the clay below the building has been effective in reducing this type of movement; however, preswelling all of the soil below a large structure is costly and time consuming. Thus, construction of some type of soil barrier is a logical alternative.

Other types of barriers have been in use within expansive soils for over 25+ years. The use of geomembranes to isolate roadway pavements has been extensively reported by Steinberg.

Alternative Design Procedure

An alternative procedure has been used by the author on large industrial structures within the Dallas/Fort Worth area for approximately four years. The procedure consists of extensively treating a strip of soil along the building perimeter (the "picture frame"). Treatment reduces the potential for movement within the zone of influence by preswelling the expansive soils and forms an isolation dam to limit the availability of moisture to interior expansive soils. Preswelling soils along the building perimeter reduces the rate of movement of the wetting front, effectively isolating the interior clay from moisture gain.

Appropriate geologic conditions should exist for application of the procedure. This alternative has been applied in profiles where expansive clay or weathered shale overlie unweathered bedrock and where thin alluvial deposits overlie weathered grading to unweathered shale. It is anticipated this alternative would not be effective where ground water is present which could influence hydration of clay isolated within the building interior.

Analysis of the effectiveness of the procedure was performed by evaluating the long-term building performance in expansive profiles where movement of the wetting front progressed inward from the building perimeter. A typical profile is shown in Figure 2. This profile developed over an approximate 28-year time frame.

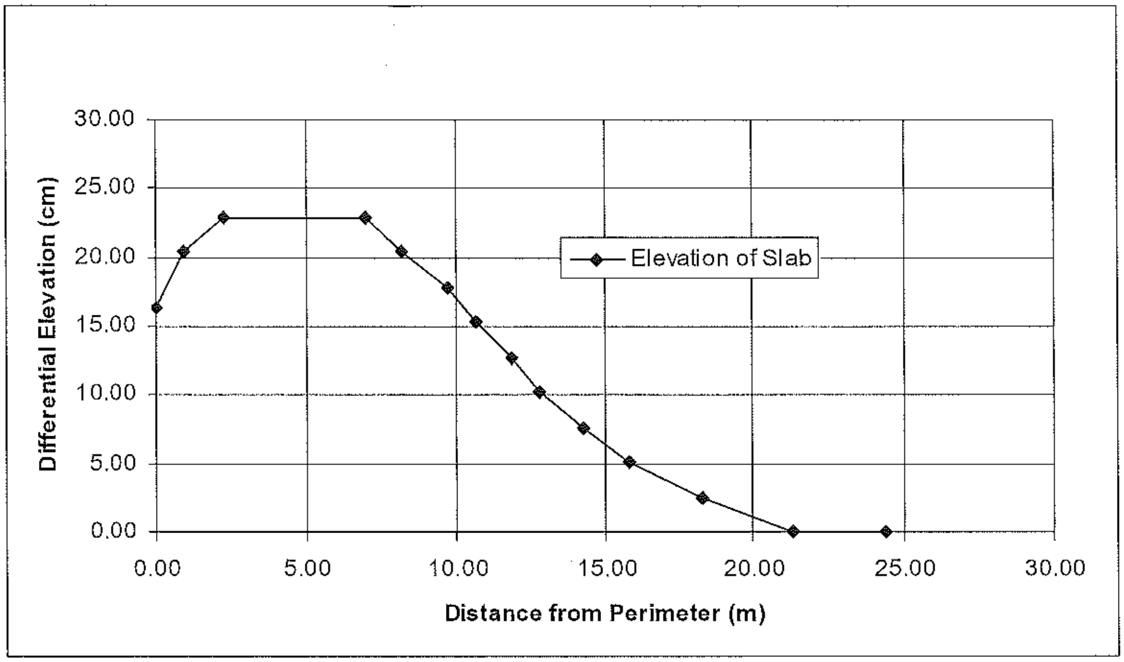

Figure 2. Typical pattern of differential movement of ground-supported floor slab where wetting front advances from building exterior to interior.

Case History

The design procedure was applied to a 59,130-sq. m. warehouse/distribution center (plan dimensions of 146 m. by 404 m.) located in Dallas within the Cretaceous Eagle Ford Shale. Subsurface conditions consisted of 2-1/2 meters of alluvial clay over highly plastic (CH) residual clay overlying dark gray shale. The top of unweathered shale was located at depths of 2 to approximately 7 meters below initial grades. A typical geologic profile with associated laboratory information is provided in Table 1. Typical absorption pressure-swell tests are shown in Figure 3. Swell tests were performed using the methods described by Johnson and Snethen.

TABLE 1.
VERTICAL SOIL PROFILE AT TYPICAL BORING

Material Description	Depth, m.	Moisture %	Total Suction, kg/m2*	Liquid Limit	Plasticity Index	-200 Sieve, %
Yellowish-Brown Clay w/Some Sand (CH)	0.5 – 1.0	17.2	115225			
	1 – 1.4	17.0	250468	70	50	93
	1.4 – 1.8	18.4	231915			
Yellowish-Brown Clay (CH) (Severely Weathered Shale)	2.75 – 3.0	17.0	198714			
	4.25 – 4.6	19.9	140125	66	45	
	5.8 – 6.0	21.1	118154			
	7.3 – 7.6	16.5	189926			
Dark Gray Shale						

*Total Suction preformed in accordance with ASTM D 5298.

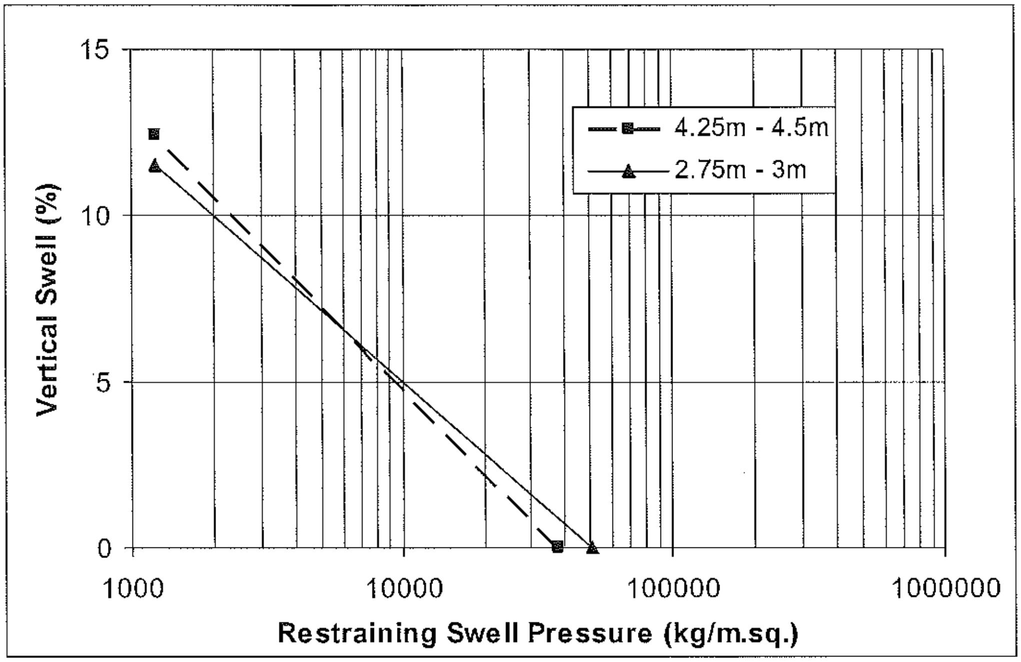

Figure 3. Typical absorption pressure-swell test result.

Proposed finished floor resulted in required cut and fill of approximately 4.25 meters each. This resulted in the top of unweathered shale varying from approximately 1.8 meters to 9 meters feet below finished floor.

Potential vertical movements were estimated to vary from 23 to 38 centimeters. This movement was attributed to 7.5 to 12.5 centimeters associated with seasonal moisture changes in the upper 1.8 to 2.5 meters, and 15 to 25.5 centimeters associated with "deep-seated heave".

Alternatives evaluated included excavation and replacement of the upper clay with "select" fill, excavation and recompaction of the clay at elevated moisture and preswelling via injection. Both the mechanical and pressure injection preswelling alternatives included a thin "select" fill or lime-stabilized cap to limit moisture loss during construction.

The alternative "picture frame" procedure was developed to reduce the amount of required remedial earthwork, saving both time and money.

Past experience indicated the majority of movement within the area occurred within the outer 9 to 12 meters of the building perimeter. Based on these observations, a design width of 18 meters was recommended. The perimeter strip was extended 4.5 meters beyond the foundation on the building exterior to reduce the potential for differential movement of site grade and paving adjacent to the foundation.

The constructed "picture frame" barrier was extended to a depth of 4.5 meters or top of unweathered shale, whichever was less. A one-meter thick blanket of compacted clay was constructed over the balance of the building pad. The purpose of the blanket was to provide limited protection against swelling of the upper soil associated with water which could pond adjacent to foundation elements during construction.

Clay blankets and sidewall protection consisting of recompacted clay were also installed along all underground utilities. Utility line excavations were recompacted for a total width of 3 meters and a minimum of 1.5 meters below the flow line of the utility. This was done to limit the potential for localized heave if a leak developed within the utility line. Clay plugs were also constructed at the building perimeter at utility entrances to reduce the potential for water flowing below the structure within pipe bedding soils.

Observation of the building performance indicates no differential movement of the floor slab to date. Although the building is only five years old, performance to date supports the viability of the "picture frame" concept.

Conclusions

An earthwork procedure, designated the "picture frame" alternative, for large structures within expansive soils has been presented. The procedure consists of construction of a recompacted earthen dam along the building perimeter to effectively reduce the availability of water to the interior clay.

For the example provided, an 18-meter wide strip, varying in depth from approximately 2 to 4.5 meters, was constructed around the perimeter of a 59,130 sq. m. building within the Cretaceous Eagle Ford Shale. Based on post-construction visual inspection, no discernible differential movement of the slab has occurred after a five-year period.

References

Johnson, L.D. and Snethen, D.R. (1978). "Prediction of Potential Heave of Swelling Soil." *Geotechnical Testing Journal*, ASTM 1 (3), 117-124.

Steinberg, M. (2000). "Expansive Soils and the Geomembrane Remedy." *Advances in Unsaturated Geotechnics,* ASCE Geotechnical Special Publication No. 99.