Second International Conference on Case Histories in Geotechnical Engineering

June 1-5, 1988

Geotechnical Engineering
St. Louis 1988

Vol. II

Editor: Shamsher Prakash

University of Missouri-Rolla
Rolla, Missouri

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 5.64

Long Term Building Performance over an Injected Subgrade

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SYNOPSIS

Several foundation designs and stabilization methods are used with varying degrees of success to cope with the problem of expansive clays. Many of these methods are very expensive, therefore alternate technology that is both cost and performance effective has been developed. This paper presents a case history with pre- and post- stabilization test data for a 4-building project where pressure injection of lime and water was used to preswell weathered clay-shale to a depth of 10 feet. Use of pressure injection technology economically reduced post construction movements to 0.5 inches to 1.8 inches over a 7 year monitoring period. Movements observed have been upward, with no settlement or shrinkage related movements related over the observed period.

INTRODUCTION

Numerous methods are employed for design and construction of buildings over expansive soils. Within the Dallas-Fort Worth (D/FW) area, methods include; suspension of the structure over the soils, with foundations placed below the active zone; composite buildings where the structural elements are founded within stable materials, and the floor is "independent" of the structure i.e. "floating"; and shallow, ground supported reinforced foundations. Movement of a ground supported floor slab must be within acceptable limits, or a non-functional building results. Likewise, movement of a shallow foundation must be limited or distress within the superstructure becomes unacceptable. Acceptable movement is owner and user defined, but in the D/FW area it is generally taken to be less than 1 inch for "floating" floor slabs and 2 to 3 inches for shallow foundations. Reduction of potential soil movements to within "acceptable" limits requires modification of the supporting soil. Some of the more common methods used in the D/FW area are listed in Table I. Costs associated with the techniques are also shown.

This paper addresses the procedures used, and results obtained on one, four-building complex within the Eagle Ford Formation. The method used consisted of preswelling the soils using a combination of lime slurry and water injection.

Initial site preparation occured in early 1981, with completion of the structures in the fall of the same year. Measured movements of the site during preswelling as well as periodic post construction floor movements are provided.

PROJECT DESCRIPTION

The project consists of a four building office/warehouse complex located in Irving, Texas, a suburb to the west of Dallas. The complex was speculative, i.e. user undefined.

Design constraints imposed by the developer included; tilt-wall construction; low rental fees; and a ground supported floor with maximum allowable movements of the floor in office areas of 1 inch, and in warehouse areas of 2 inches. Warehouse and offices in the immediate area had experienced floor movements in excess of 10 inches. (Reed, 1985) The method used for stabilization typically consisted of over-excavation and replacement with inert fill. Modifications to this method included providing a lime stabilized 6 to 12 inch layer below the inert fill.

Initial site topography required cut and fill earthwork to achieve desired finished grades.

TABLE I
Summary of Techniques used for "stabilizing" near surface soils

Techniques	Applicable Depth (feet)	Cost/ft^2	Comments
Excavate existing soils, mix with lime and recompact	3 to 5	\$1.60 – \$1.90 (3') \$2.50 – \$2.90 (5')	
Overexcavate and replace with inert, non-expansive soil	3 to 7	\$1.25 – \$1.40 (3') \$2.90 – \$3.20 (7')	If inert materials are permeable, can result in ponded conditions below grade.
Pressure Injection	10 to 15	\$0.72 (2 Lime & 2 Water) \$0.45 (1 Lime, 3 Water)	Requires more rigid engineering control during earthwork. Greater depths are possible. Slower then overexcavating and replacement.

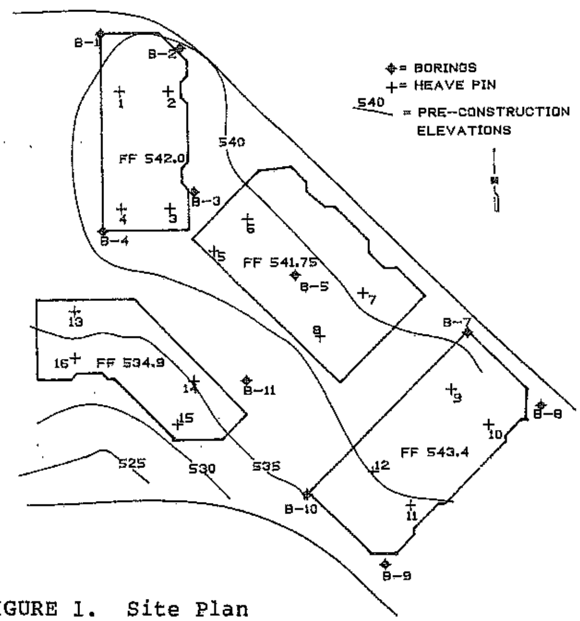

FIGURE 1. Site Plan

associated with stress reduction, cut within building areas was limited to one of the four structures. Initial site contours and finished floor elevations are shown in Figure 1.

The initial design for the project encorporated the use of 3-1/2 feet of inert fill over six inches of lime stabilized clay. This technique was rejected by the owner because of poor performance related to excessive floor movement on projects in the general vicinity.

The use of pressure injection was considered as an alternative, however it's use was initially rejected because of a "feeling" by various consultants that the soils were too hard and dry to effectively inject. Due to the historical performance of other proposed modification techniques, however, the owner elected to pursue injection. A monitoring program to evaluate the effectiveness of both the injection operations and post-construction floor performance was therefore established.

In order to reduce the risk of movement at entrances to the office areas, a suspended floor system was used. Other design modifications included use of one site clays for backfilling trenches and utilities in place of sandier, more permeable soils.

GEOLOGY

The site is underlain by soils and shale of the Eagle Ford Group, a marine, montmorillonitic clay shale of Upper Cretaceous age. The shale is thinly laminated, gray to bluish-gray in color and weathers to tan to olive tan and gray with ironstaining along joints and fissures. Depth of weathering across the site varies from 29 to 40 feet. Ground water was not encountered during the initial geotechnical investigation, although intermittent perched water is anticipated to be occasionally present along the weathered/unweathered interface during rainy seasons.

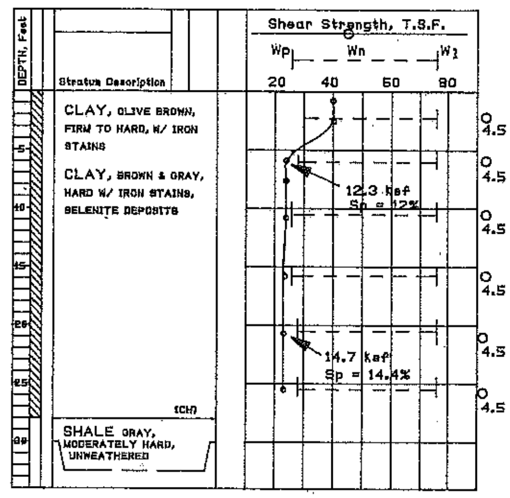

FIGURE 2. Typical Stratigraphy & Soil Moisture Profile

Weathering of the clay-shale results in a tan to olive-tan and gray residual clay. The clay retains the shales' laminated fabric, and is jointed and fissured on spacings of 2 to 8 inches. The joints and fissures are commonly ironstained and occasionally silt lined.

The upper 3 to 9 feet of clay soil is subjected to variations in seasonal soil moisture, but these values are less than the average for the Dallas metroplex which is generally estimated to be on the order of 12 to 15 feet. The reduced seasonally active zone is considered to be primarily a result of the sloping site topography, the relative low permeability of the clay soils, and the jointed structure.

TABLE 2
SUMMARY OF SOIL PROPERTIES

PROPERTY	UNITS	POPULATION	RANGE	MEAN	DEVIATION
Liquid Limit, w_l	--	16	48 - 86	69.8	8.51
Plastic Limit, w_p	--	16	22 - 38	32.2	4.61
Plasticity Index, I_p	--	16	26 - 56	37.6	7.43
Dry Unit Weight, d	pcf	27	84 - 108	99.6	6.83
Wet Unit Weight, w	pcf	27	110 - 133	124.2	5.92
Specific Gravity, G_s	--	3	2.79 - 2.93	2.85	0.03
Saturation, S	%	12	87 - 97	92.0	0.03

The natural moisture content of the clays below the seasonal influence is 4 to 7 percentage points below their plastic limit. The moisture content generally decreases with depth, as is common in weathered shales. An example of a typical Log of Boring is shown in Figure 2. This figure illustrates moistures above the plastic limit to a depth of about 5 feet, and soil moisture below the plastic limit below this depth. Also shown in figure is the maximum pressure (Ps) and the percent swell at overburden, (Sp), from the result of two Constant Volume Swell tests.

The weathered shale classifies as a CH soil, in accordance with the Unified Soil Classification System. The consistency varies in the zone of seasonal moisture, becoming hard below this zone. A summary of some of the pertinent soil properties is provided in Table 2.

CONSTRUCTION SEQUENCE

Finished floor subgrade elevations, minus 5 inches, were initially established in January 1981 utilizing on-site clays as fill. The subgrade was left 5 inches below desired subgrade to account for the desired pre-swelling of the upper soils.

Materials were compacted in approximate 10-inch lifts to a density of between 90 and 95 percent of ASTM D-698, at a moisture wet of optimum. Four heave pins were then installed on each building pad with the base of the pin 18 to 22 inches below grade. Heave monitoring pin locations are shown in Figure 1. Pin elevations were obtained and tied to a bench mark founded at a depth of 25 feet below grade. The bench mark was sleeved throughout the upper soils to reduce uplift.

Pads were then double lime slurry-pressure injected, followed by 2 water injections, to a depth of 10 feet on building pads A thru C, and 3 water injections on building pad D. Continuous undisturbed Shelby tube samples for moisture content tests were obtained to a depth of ten feet after each water injection. Heave monitoring pins were surveyed after each injection.

FIGURE 3. Exposed lime seams in face of excavation.

Upon completion of the injection operations, the near surface soil were blended with the surficial lime, compacted, and brought to grade. Utilities were then installed. Construction then proceeded in a normal manner.

RESULTS

Injection procedures progressed normally throughout the project. Adequate dispersal of lime was observed. Some of the exposed seams of lime are shown in Figure 3.

The change in measured soil moisture and the measured heave during injection on two of the four buildings are presented in Figures 4 and 5, and 6 and 7, respectively. Test results are typical for all four buildings.

Measured heave below the survey pins varied from approximately 0.75 inches to 3.50 inches. Actual heave is anticipated to be on the order of 5 to 6 inches because approximately 1 to 2 inches of soil had to be cut from the pads at the completion of injection operations to achieve desired subgrade. As previously

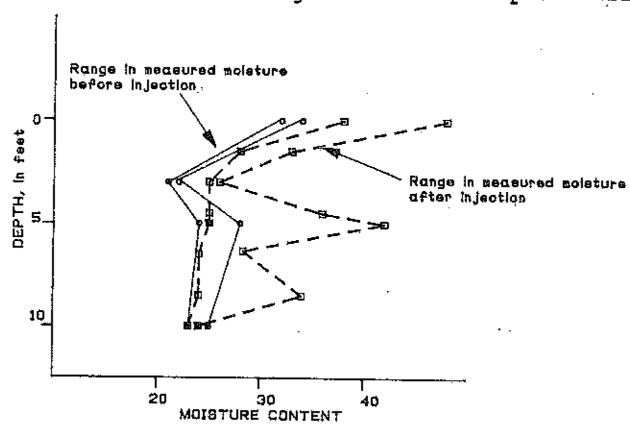

FIGURE 4. Rise in moisture after 2 lime and 2 water injections, Building A

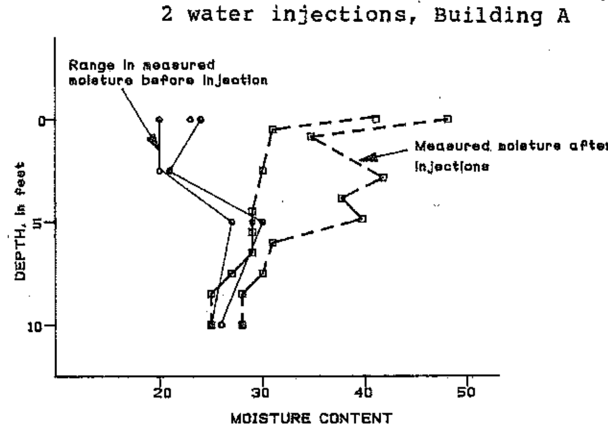

FIGURE 5. Rise in moisture after 2 lime and 3 water injections, Building C.

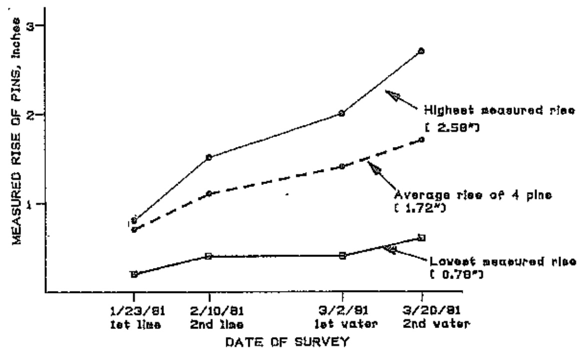

FIGURE 6. Measured rise in elevation of Pad Survey Pins during construction, Building A.

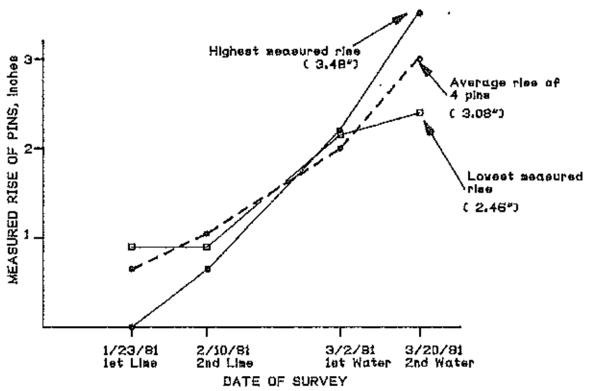

FIGURE 7. Measured rise in elevations of Pad Survey Pins during construction, Building D.

mentioned, subgrade before injection was left 5 inches below desired finished grade to account for heave.

Post construction floor movements have been within acceptable limits, with measured heave through September of 1983 varying from about 0.5 inches to 1.8 inches. Measured heave in building A is shown in Figure 8. Based on visual observations, much of the measured heave is attributed to survey error, and/or movement of the bench mark.

To confirm the visual results, 21 profiles of the floor in buildings A and B perpendicular to the walls were monitored from June 1982 through September 1983. Typical results for one station

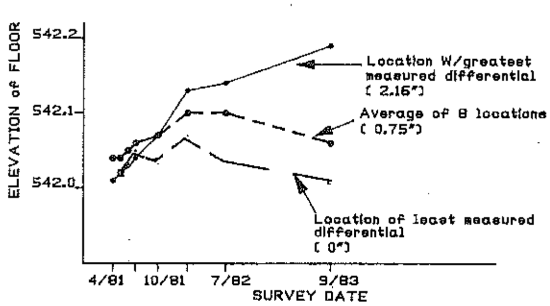

FIGURE 8. Measured post construction floor movement, Building A.

are plotted in Figure 9. The profiles indicate equal differential movements across the floor. Since it is extremely unlikely that movements would be uniform, the difference in elevation over the period surveyed was attributed to survey error. Corrected movements for building "A" are shown in Figure 10. The monitoring through 1983 indicated no appreciable movement, and was therefore discontinued.

Periodic site visits have been performed since completion of the monitoring program. No distress or differential floor movement has been detected or reported.

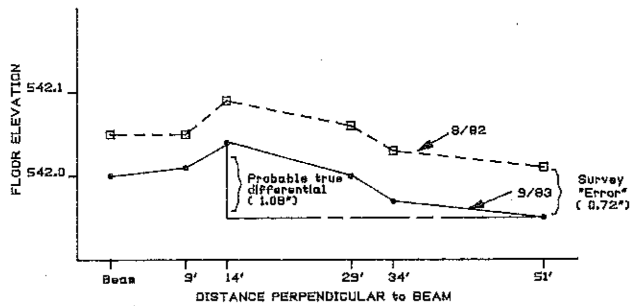

FIGURE 9. Measured movements perpendicular to perimeter wall, Building A at location 4.

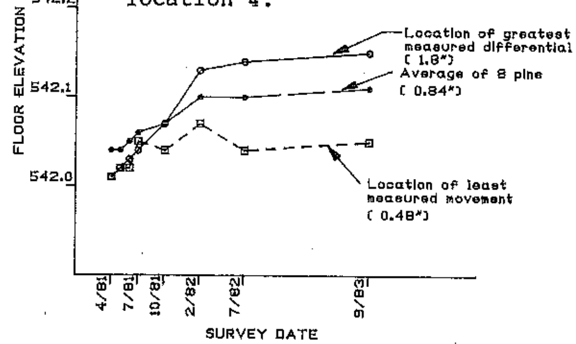

FIGURE 10. Floor movement, Building A, Corrected for survey error between 7/82 and 9/83.

CONCLUSIONS

1. Effective reduction of the potential vertical movement of the upper soils of the Eagle Ford formation was obtained by using a combination of lime-slurry and water pressure injection.

2. Construction monitoring of the subgrade indicated heave as a result of injection operations on the order of 2 to 4 inches.

3. Post construction monitoring of the floor slabs over a seven year period indicates movements of 0.5 to 1.8 inches, which are within design tolerances. No post construction settlement or shrinkage has been experienced.

4. Costs for the injection modification were approximately one-half compared to costs associated with other techniques used in the D/FW area. Performance of the injected project has been superior to that experienced on projects in the immediate area.

REFERENCES

Reed, F.R., (1985), "Foundation Performance in an Expansive Clay", Proc., 38th Canadian Geotechnical Conference, Theory and Practice in Foundation Engineering, Edmonton, Alberta, pg. 305-313.