Remedial Treatment of a Slab on Clay Using a Lime–Fly Ash Curtain

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A case history is provided of a slab on grade that has experienced significant differential and damaging movements caused by the swell of highly active clay soils. The damage is illustrated by profiles of the slab. Measures taken to stabilize the slab movements using moisture stabilization by installation of a lime–fly ash grout curtain are included. Relative elevations of the slab were determined to warrant the repair measures, which included establishment of a deep benchmark, measurements of elevations of the slab, and the injection stabilization. More than 1 year of elevation surveys are described. This information, along with personal accounts of those using the slab, indicates that foundation movements have essentially ceased.

It was projected by Baer that by the year 2000 the average total building losses from natural causes would be $12 billion (1978 dollars) (*1*). In fact, the damage caused by expansive soils at the time of his study was the second most costly (along with hurricane wind and storm surge) among America's most destructive natural hazards, surpassed only by riverine flood. He predicted that expansive soil damage would cost more than $4.5 billion by 2000. Expansive soils are known to exist in all 50 states; 20 percent of the nation's families live on such soils. The transportation facilities of most states are, therefore, affected by the damaging behavior of these soils. In 1975 Snethen et al. reported on the widespread experiences of transportation engineers with expansive soils (*2*).

Many new construction and remedial methodologies have attempted to overcome the behavioral problems presented by these materials. The use of vertical barriers against moisture movement to stabilize moisture levels in highly active clays under slabs has progressed, but it is not generally in widespread practice. This is a report on the use of one such barrier to stabilize slab on grade on the campus of the University of Texas at Arlington (UTA). This relatively thin slab on grade is very similar in behavior to those of pavement sections and other light transportation-related buildings. The fact that the superstructure loads are carried by piers around the slab makes it act much the same as transportation slabs. The conclusions of the reported study support additional use of such treatments for both light building slabs and pavements.

BACKGROUND

Early in the 1970s, Poor studied the concept of stabilizing highly active clays by controlling their moisture contents through moisture movements barriers (*3,4*). Both horizontal (ground surface) and vertical (subterranean) barriers were studied and were found very effective, especially in the moisture-variant climate of Texas. The membranes used by Poor were constructed of recycled rubber, clean gravel, and well-densified lean concrete. He found the second two of these membranes to be most effective for stabilizing slabs on grade. The 1979 report of Forstie et al. described the use of asphalt membranes for the control of moisture in expansive clays (*5*). They reported greatly improved long-term ride performance from shoulder and ditch membrane treatments. In 1979, Snethen reported on technical guidelines for use of expansive clays in highway subgrades, including asphalt membranes to seal the subgrade as well as horizontally and vertically placed synthetic fabric membranes (*6*).

Steinberg has provided long-term reporting, 1981 through 1989, on the success of using vertical barriers to moisture movement along highway pavements in San Antonio, Texas, to stabilize expansive clays (*7–9*). In each case where these have been applied, the maintenance and long-term rideability of pavements have significantly improved. Gaye and Lytton reported the effectiveness of lime–fly ash grout curtains as well as other techniques in stabilizing expansive clay pavement subgrades (*10*). They found the 10-ft-deep grout curtain to be superior to shallower vertically placed fabric membranes. It is because of these reports that such a grout curtain was chosen to stabilize the slab on grade on the UTA campus. It is not understood why more vertical membranes of this type and others are not in use along pavements and around slabs on grade, except for lack of adequate knowledge of this treatment. The following case history is made available to increase awareness of the advantages of the technique.

CASE SITUATION

Late in 1985 construction was started on the Aerospace Engineering Research Laboratory at UTA. Before that time it had been recommended that, because of the expansive nature of subgrade soils, the foundation of this one-story building be a mixture of two types. The superstructure is founded on straight shafted piers based on a shale layer 22 to 25 ft into the subgrade. Grade beams suspended 8 in. off the subgrade and supported by the piers provide support for the tilt-up wall and steel-frame roof system. The interior slab on grade is supported on 2½ to 3 ft of select fill material that was put in place after excavation of a similar depth of natural soils. These select fill materials would be expected to have a liquid limit of less than 30 and plastic index between 4 and 12 and would be classified as an SP-SM by ASTM and an A-2-4 by AASHTO.

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They were placed there to reduce significantly the swell potential of the subgrade and provide a place for misdirected drainage to accumulate. This select fill and the slab are shown in Figure 1, which includes the soil profile under them.

The natural soil profile consists of materials weathered from the Woodbine geologic formation, which is a typically dense and hard river delta and shallow sea deposit. These materials are known to be highly variant, vertically and horizontally. They often contain layers of materials that vary from pure sand to pure highly active clays. At this site the near-surface layers, to depths of between 7 and 8 ft, are sandy clays and silty sandy clays. These materials would be classified as CLs and A-6s or A-7-5s. These are overlying silty shaley clays to a depth of 22 to 25 ft. These deeper clay soils would be classified as CLs or A-7-5s. Below these depths is a shale of significant thickness that has sand seams in it and that probably overlies a cemented sand. The soil materials in this profile have significant percentages of sand in them so that their Atterberg limits only partly represent their potential for volume change, especially since they are relatively dense materials. Their liquid limits range from the upper 30s to the upper 50s, and their plastic indexes, from about 20 to about 38. Their swelling potential was significant before construction, because they were fairly dry even at depth and construction began near the end of a dry time of the year. In addition, it had been reported that, for some time in the past before construction of this building, there had been a slow-flowing spring on the property. It is unknown where it is in relation to the building; it may even be under it.

Construction of the building began late in 1985, before the wetter portion of the year. The structure was complete and occupied by December 1986. A plan view of the facility is given in Figure 2. The first cracks were noted in interior sheetrock walls in February 1986. The first area affected was near the north end of the building and in the room just west of the north-south hallway. One of the possible problems noted, as part of the early analyses, was poor drainage on the west side of the building from the north end and especially in the flower bed south of the part of the building west of the north-south hallway. In these areas, sprinkling systems and poor drainage caused concentrated wetting of foundation soils, as indicated by laboratory personnel. Even though the use of sprinklers was eventually stopped, the foundation movements continued. In April 1988, the Civil Engineering Department was notified of the problem and the author became involved in surveying the situation and recommending remedial actions to be taken.

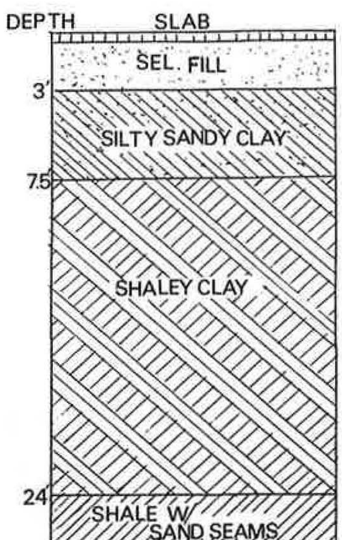

FIGURE 1 Cross section of slab and soil profile.

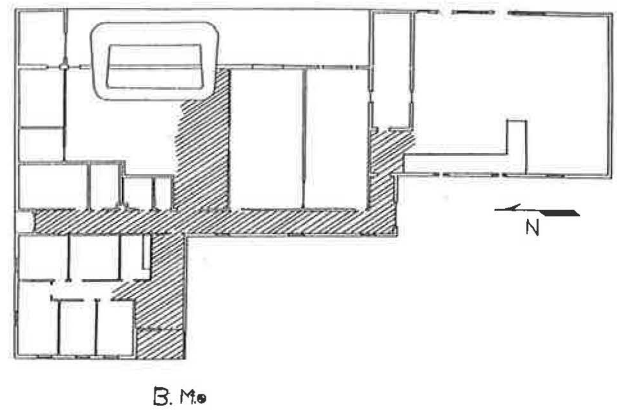

FIGURE 2 Plan view of slab on grade and building.

The first survey of relative differential elevations and damage was taken in May 1988. It is important to note that at this time no deep benchmark existed at the site. Using a water-level system, the geotechnical engineering group measured the relative levels of 270 positions of the slab. The results of this survey are shown in the topographic map in Figure 3. The contour interval is 0.3 in. The odd contour lines, representing differentials of 0.3, 0.9, 1.5, 2.1, and 2.7 in., are solid, and the even ones, for 0.6, 1.2, 1.8, 2.4, and 3.0 in. of differential, are shown as dotted lines. At that time, the maximum differential elevation in this slab was nearly 3 in. The largest slopes in the slab can be seen to be in the area where damage was first noted, whereas the south end of the building appears to have few and small differentials. As a part of this survey, holes were cut through the slab and samples were taken.

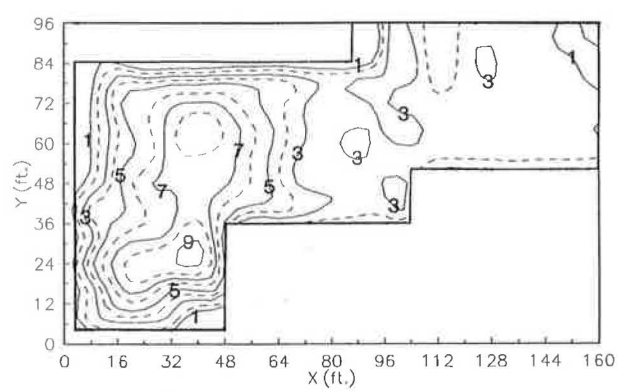

FIGURE 3 AE building elevations, May 5, 1988.

The materials found during this sampling were as expected and in accordance with the design. The top 2½- to 3-ft layer was made of select sandy fill materials with very low plasticity; the rest was nearly as described in the preceding paragraph. These materials, however, still had a swelling potential of about 1 in., according to swelling tests performed. One of the most significant findings was that the select fill materials were saturated to significant heights above the natural clay subgrade. There was, therefore, much concern that not only the near-foundation materials, but also those materials at greater depths would swell. This potential deep-seated swell, which would not be expected unless water ponded in the select fill could reach materials over time, was sure to be very damaging.

A further cause for concern was that the swell happened so quickly after construction. This was probably due to the relatively high soil mass permeability of the fissured sandy soils; it was also a forewarning that more-damaging swell could occur sooner than expected. For these reasons, it was deemed necessary for remedial actions to be taken as soon as possible.

REMEDIAL ACTIONS

The remedial actions recommended by the geotechnical engineering group of the Civil Engineering Department included correction of the remaining, concentrated wetting activities; establishment of a permanent benchmark on the property; monitoring of slab levels on a continuing basis; installation of a lime–fly ash grout curtain where needed; installation of a permanent drain system for the select fill; and eventual repair of the structure. The first of these was completed fairly quickly and included correcting drainage, where needed, to carry all surface waters away from the building. There were driveway slabs all along the back or east side of the building that acted as horizontal moisture change barriers. Monitoring of elevations began as soon as the benchmark was placed in the spring of 1990. The intervening years had gone by because UTA wanted not only to see what would happen but also to give the drainage corrections a chance to work. UTA authorized further remedial activities, since the problem seemed to be worsening.

Injection of the lime–fly ash grout curtain was done in April 1990 by the Woodbine Division of Hayward Baker Incorporated. The forklift used for this purpose is shown in relation to the building and as it injected the grout, in Figures 4 and 5, respectively. This injection was done to a depth of 10 ft at 5-ft intervals along two single lines such that the resultant intervals were 2½ ft and the curtain was two lines thick around the north, west, and south sides of the building, lime–fly ash grout contained a surfactant and 7 lbs of dry material per gallon consisting of 1 part lime to 3 parts fly ash, the grout was injected to refusal at each foot of depth during the process. The total volume of slurry injected was 16,000 gal. A considerable amount of groundwater was being ejected from the soil mass during this process. It was possible to move the forklift easily around the building and the shock wave tubes of the high-speed wind tunnels on the west, or front, side of the building. The injection process was completed in 1 day.

The permanent benchmark installed consists of a No. 8 reinforcement bar 20 ft long that was driven 5 ft into the subgrade in a predrilled hole cased with 15 ft of PVC pipe. A cap was placed over the top of the pipe at a depth to prevent mower damage. Elevations of parts of the building, as indicated in Figure 1, were taken before the injection process, they have been and will be monitored monthly until stabilization of the foundation is deemed finished. When the building is believed stable enough, recommendations for repair of interior damage will be enacted.

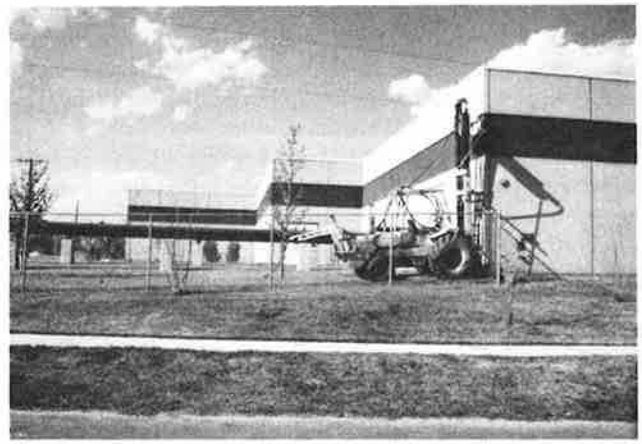

FIGURE 4 Grout injection forklift in relation to building.

FIGURE 5 Injection of lime–fly ash grout.

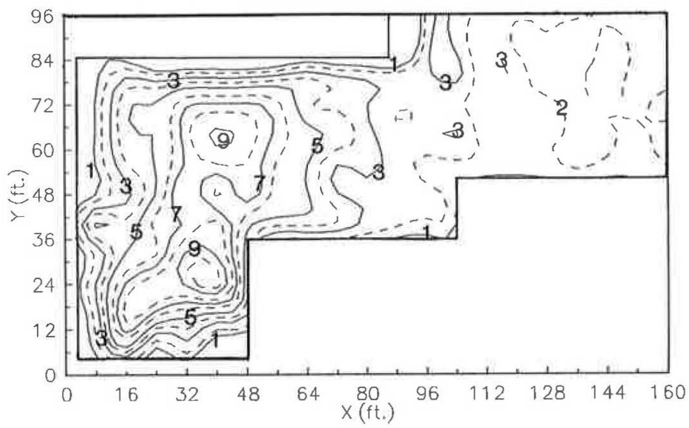

FIGURE 6 AE building elevations, June 11, 1991.

REMEDIAL RESULTS

The success of remedial actions taken in this case is indicated by two kinds of survey information. The first of these is from intermediate elevation surveys. The initial intermediate survey was done a few days before the injection process and another was accomplished within 2 weeks of injection of the grout curtain. These surveys consisted of measuring the elevation relative to the benchmark at 58 points up and down the north-south hallway, in the entrance foyer and back into the low-speed wind tunnel laboratory, and, to some extent, into the high-speed wind tunnel laboratory. The areas covered are shown in Figure 2. Elevation changes were found to have occurred between these two surveys, as expected for the effects of the injections. The sizes of these changes were not considered significantly damaging, especially when compared to what had already occurred; in addition, they were more uniform than those which had happened previously. The highest amount of change was 0.11 ft, but most were around 0.05 ft. During this same time, the elevation of water in the select fill was monitored. Three holes through the slab, where samples had been taken earlier, remained open and although these water levels were measured, the water was bailed out and the return of water was noted. In all but one location, the select fill was found to be drying out. That one remaining hole in which water continued to appear is thought to be near the natural spring described earlier.

The remaining intermediate surveys taken to date have shown little, if any, further movement of the slab. The sort of changes noted from month to month have been all 0.03 ft and less, with most being zero. It is believed that almost all of these values are generally within the accuracy of the leveling process used to determine them. It is believed that this slab has essentially ceased to move, and that the foundation soils have reached stable moisture levels for the present situation.

The second type of information was determined during a level survey of the whole slab done in June 1991. The results of this survey are given as a topographic map in Figure 6. The contour intervals shown in Figure 6 are the same as those in Figure 3. It can be seen that some additional differential movements have occurred, but the shape of the slab is nearly the same as in 1988. The maximum differential is still 3 in., the major differentials are found in the same places, and the south end of the building has remained relatively level.

When considering both types of elevation survey information, it can be determined that the slab in consideration has not moved in any significant way since the injection of the lime–fly ash grout curtain and that this curtain has assisted in maintaining stable moisture levels in foundation soils. The history of movements in this slab was one of large-scale differentials during the first year of the structure life and less damaging ones up to injection of the stabilizing curtain. The deflected shape of the slab on grade has remained nearly as it was before injection, and this may well provide the opportunity for repair in the near future.

CONCLUSIONS

Considering the information developed about vertical moisture movement barriers and the results presented herein from the remedial actions taken for the slab on grade under study, the following conclusions are made.

1. The reason for the differential movements noted for this slab on grade is the swelling of expansive clay soils upon which the slab is founded.
2. The sources of water that have caused the differential wetting described were poor drainage, improper watering techniques and a possible slow-flowing spring.
3. The installation of a lime–fly ash grout curtain around this structure caused initial relatively small and fairly uniform movements.
4. The installed lime–fly ash grout curtain has provided a barrier that has prevented significant moisture change in foundation soils.
5. The resulting slab on grade foundation system is reasonably stable and is nearly ready for final repairs to the building interior.
6. A lime–fly ash grout curtain is a practicable alternative to be considered for use in the stabilization of transportation facilities on expansive clay soils, whether they be pavements or other types of slabs on grade.
7. More reported use of this type of barrier, both in research and field construction, is needed to raise the awareness

of those who can benefit from their use in transportation facilities.

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