CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Introduction

Foundation distress and subsequent failure will continue to be a problem for homeowners, especially when they are built in expansive clay soils. As a result, underpinning to mitigate deflection problems for slab-on-grade foundations in contact with these expansive soils will continue to be remedial measures adapted in the field. Because of the wide spread use of piers, piling and helical piers, this research was undertaken to address the axial load transfer mechanisms in these foundations. This research will be helpful to provide insights to the practitioner, engineers and homeowners while deciding the proper method of underpinnings for foundation repairs. It should also be mentioned that the research results and conclusions can be further corroborated by conducting additional studies on different expansive soil sites.

The major conclusions and summary information from the present study are summarized in the following section.

8.2 Summary and Conclusions

The following conclusions and summary information was obtained from this research conducted on six different underpinning systems installed in an expansive soil zone.

8.2.1 Summary

1. Predictions of axial compression capacity of the drilled shafts, belled piers and augercast piles were close to measured capacities. Hence, the pier or pile capacity procedures using the FHWA-IF-99-025 design manual (FHWA 1999) are considered reliable methods for estimations of axial capacities of these foundations in expansive soil media.
2. Use of a 60^o layout plan for field testing of large numbers of piers and piles was proven to be effective and efficient in the field load testing operation.

8.2.2 Conclusions

1. There was a negligible difference between ultimate axial compression capacity in the straight drilled shafts and augercast piles. The skin friction allowance for the drilled shafts should be the same as the one allowed for augercast piles in clay soil. Also, the deflection readings at ultimate capacity were slightly greater for the augercast pile than for the straight or belled shaft. This difference may be attributed to construction procedures in that the augercast pile normally does not produce a clean bottom surface whereas in a drilled shaft, the bottom surface can be inspected before placing concrete by either looking in the hole or running a camera in the case of open holes and by probing when pouring under slurry.
2. There was a negligible difference in ultimate axial compression capacities of the majority of drilled underpinnings between ‘dry to wet’ and ‘wet to dry’ seasonal conditions. While shear strength in upper layers did increase while

going from 'wet to dry' season, drying induced soil shrinkage from the pier/pile (near surface) might have mitigated the increases in axial capacity.

3. Time of soil sampling has a major bearing on predicted axial compression capacity. If insitu or soil sampling tests is made during the dry season, shear strength parameters might have been increased for upper clayey layers due to desiccation related drying. Conversely, the wet season strength parameters are low and may provide lower, but conservative design parameters.
4. This research also indicates that the non-contributing depth of soil considered for shafts appeared to be important when foundation tests were performed in dry season. The non-contributing lengths from thin wire measurements show that they vary from 3 ft to 4 ft, slightly less than the recommended 5 ft value. If soil sampling and testing is attempted in the wet season, this research indicates that the total shaft depth should be included in the predictions of axial capacity since soil around the upper layers is in contact with shafts.
5. Installation of helical piles shows that the installation process of the helix in clayey medium may not pull into the ground efficiently to prevent augering of the helix and thus producing a trailing section of loose soil. Therefore the helical anchors will many times require seating using pressure from a structure in order to obtain the maximum capacity of the helical piles. With the presence of this void, larger deflection in helical piles installed in new construction jobs must be anticipated in clay soils and the design engineer must allow for this deflection accordingly.

6. In this research, when the installation torque was constant and same for helical piles, there was minor or very little difference in ultimate axial compression capacity between single and double helix piles. The double helix piling did, however, produce a more consistent ultimate capacity.
7. There was no obvious or major difference in the ultimate axial capacities of the helical piles installed in 'dry to wet' and 'wet to dry' conditions.
8. The Individual Bearing Plate method proved reasonable approach in estimating capacity of the single helix. With the double helix, however, it is necessary to apply a disturbance factor to be included in the axial capacity formulation to simulate disturbed state of soil condition. This disturbance factor was found to be an approximate 80% for this research. Therefore, contributing axial capacity support of the trailing helix was only 20% of the leading helix capacity as measured by area of helix and shear strength of soil.
9. Pressed steel pilings show the greatest amount of deflection prior to reaching their ultimate capacity. Both pressed concrete and steel piling systems yielded consistent at their ultimate capacity when they were installed during the wet period. Deeper penetration depths for these pressed piles were obtained, which indicate that the final capacity of these piles depend on length of the pile, and installation as well as testing seasonal conditions.
10. Pressed concrete pilings appear to perform in an identical fashion as those of drilled concrete piers but with an obvious reduction in axial load capacity due to smaller size of the pressed concrete pile dimensions.

11. When pressed concrete pilings were installed shallower than the zone of seasonal moisture change (between 10 ft and 15 ft for this test), they tend to loose most of the installation capacity, i.e. up to 42% of the installation load. When these same pilings are installed below 15 ft in this soil and in these climatic conditions, they have gained 37% over installation capacity.
12. Three of the final six pressed concrete pilings were broken either during installation or during testing. It is not known if this failure was due to the movements of reaction beam or due to bending moments caused by lateral soil shrinkage around the piling during the dry period.
13. The pressed concrete pilings used in this research were installed with a #4 reinforcing steel bar passed through the center of the piles with the hole filled with Portland cement grout. Both reinforcement and grouting enhance lateral load resistance as well as flexural capacity of this foundation system. Hence, the present pressed concrete pile results are valid for this type of pressed concrete pile system. The performance of pressed concrete pilings without any reinforcement or bonding may have problems simply due to lesser tensile and flexural resistances.
14. Predicting axial compression capacity of pressed steel pilings does not appear to be accurate when using soil properties from laboratory tests on samples collected from the field. When the continuous CPT profiling with side friction measurements was used to estimate the capacities, they appear to match with the measured ultimate loads. This correlation is especially strong when the pilings were installed sufficiently below the active zone. This indicates that

soil is around pressed piles are in residual shear strength state, which is well captured by the side friction of CPT. Also, the mechanisms of penetration for pilings and CPT are similar and hence there is a strong correlation between side friction estimation in both methods.

15. Overall comparisons of the six underpinning methods show that the belled shaft has the highest axial load capacity followed by the straight shaft and augercast piles. Though cost comparisons are not included here, it can be qualitatively mentioned that the costs of drilled shafts and augercast piles for underpinning can be significantly high in expenses when compared to the rest of the underpinning methods. However, the final selection of the underpinning foundation system should not be based on the cost of installation and construction of them. Such practice may lead to further problems to residential structures in the future.

Excerpt from "Load Capacity Testing and Analysis of Residential Underpinning Systems in Expansive Clay Environment" by W. Tom Witherspoon