UPLIFT ON DRILLED SHAFTS IN SWELLING CLAYS
Summary Findings

CONSORTIUM FOR EDUCATION AND RESEARCH IN GEO-ENGINEERING PRACTICE
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Background:

When drilled shafts are installed in shrink-swell soils, an uplift tension force can be generated by the swelling of the soil towards the upper part of the pile. Typically, the shaft will extend down to a non-swelling layer, therefore the upper portion of the shaft will be subjected to uplift forces while the lower portion is resisting the upward forces. There are several opinions, methods, and approaches to design for this phenomenon. This is a summary of the findings on this topic including the methodologies available to estimate the uplift force applied by the swelling clay on the drilled shaft followed by a full scale test on two drilled shafts in a swelling clay near San Antonio, Texas.

What the researchers did:

In a first part, a literature review is conducted on the current design practice to calculate the uplift force generated by swelling clays on a drilled shaft. Design examples are worked out for each method in order to compare the values obtained. Two full scale case histories are presented one on a 1982 instrumented drilled shaft at Lackland Air Force Base, near San Antonio, Texas and one from a site in South Africa. The design methods discussed are also compared to what was found in the two case histories.
In a second part, the researchers performed a field swell test on one of two drilled shafts at the A.H. Beck yard in Converse, Texas, near San Antonio in collaboration with A.H. Beck and Intertek PSI. Regular strain and surveying readings were taken and analyzed to monitor uplift forces development. The field work was complemented by laboratory testing.

What the researchers found:

Calculating the uplift load consist of a series of steps. The first step is to identify the shrink-swell soil through soil tests. The second step is to determine the depth of the active zone. Determining the depth of the active zone was the topic of CERGEP report no. 8 (Chen et al., 2019). The final recommendation in that project was to use a map of Texas giving the depth of the active zone at any location and based on a survey of the CERGEP members. The third step is to estimate the interface maximum friction f_{max} between the soil and the drilled shaft. The most common method (FHWA) is based on the undrained shear strength of the fully softened soil s_{usoft} multiplied by a factor α equal to about 1.

$$f_{max} = s_{u\text{-}soft}$$

Effective stress approaches give the interface friction as the effective stress swell pressure σ'_s multiplied by a factor β equal to 0.15 as an average of the recommendations; however, the effective stress approaches, while more theoretically satisfying, lack measured data to calibrate it.

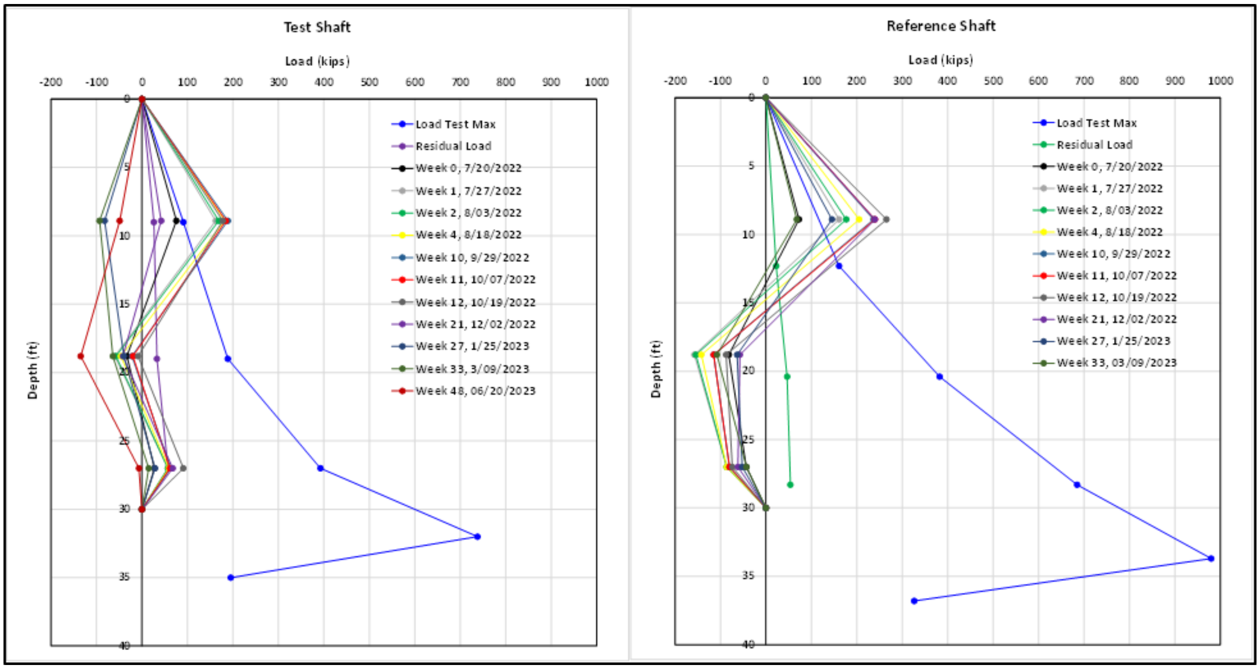
$$f_{max} = 0.15\ \sigma'_s$$

The case study at Lackland Air force base, near San Antonio, gave a back-calculated α-value of 0.59. The drilled shaft was 2.5 ft in diameter, embedded 36 ft in a swelling clay including a 4 ft diameter bell to anchor it. It was built in 1966 and left untouched. It is surmised that a crack developed above the bell and gave an independent measure of the uplift friction during the load test. The case study in South Africa gave a back-calculated α-value of 0.34, however the undrained shear strength was not measured directly but inferred from the CPT point resistance. The two instrumented straight drilled shafts were 1.48 ft in diameter and 54 ft long. One was left intact and served as a reference shaft, the soil around the other one was inundated for 6 months.

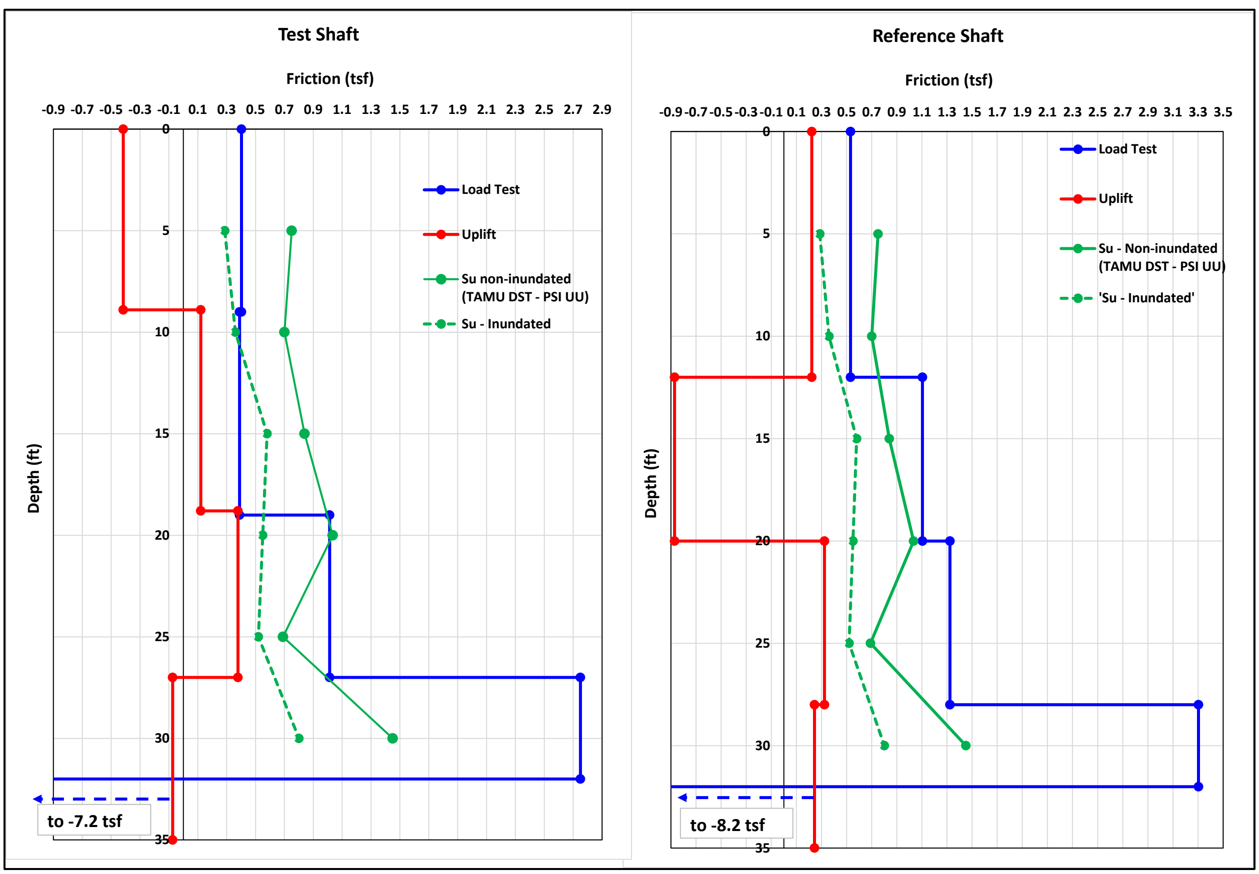
In this project, a pair of instrumented straight drilled shafts were tested for uplift due to the swelling clay near San Antonio. The back-calculated α-value was 0.51. The drilled shafts were 4 ft in diameter and 35 ft embedded in the clay. One was left intact as a reference shaft and the soil around the other shaft called the test shaft was inundated for 4 months with little change. Then four holes were drilled down to 15 ft feet within the inundation zone to facilitate access of the water in the clay. Swelling took place and generated uplift friction in the top 15 ft. The load distribution after almost a year of observation for both shafts is shown below along with the undrained shear strength and maximum friction profile. The load profiles indicate that the drilled shaft was in compression during the dry months followed by uplift tension once effective inundation was induced. Considering the results of the two published case histories and the tests on two drilled shafts in this project it appears reasonable to recommend the following alpha values:

- $\alpha = 0.5$ for swelling uplift friction when using the not-inundated undrained shear strength
- $\alpha = 1.0$ for swelling uplift friction when using the undrained shear strength where the sample is inundated for 24 hours before shearing
- $\alpha = 1.0$ for shrinking downdrag friction when using the not-inundated undrained shear strength

This value is consistent with the recommendations of the Foundation Performance Association in Houston. It also corresponds to an α value of about 1 applied to the fully softened undrained shear strength as recommended by FHWA; indeed, in this study, the fully softened undrained shear strength was found to be about one half of the intact undrained shear strength. The effective stress approach is not recommended at this time as it lacks verification.



Test Shaft
Load (kips)
Depth (ft)
Load Test Max
Residual Load
Week 0, 7/20/2022
Week 1, 7/27/2022
Week 2, 8/03/2022
Week 4, 8/18/2022
Week 10, 9/29/2022
Week 11, 10/07/2022
Week 12, 10/19/2022
Week 21, 12/02/2022
Week 27, 1/25/2023
Week 33, 3/09/2023
Week 48, 06/20/2023
Reference Shaft
Load (kips)
Depth (ft)
Load Test Max
Residual Load
Week 0, 7/20/2022
Week 1, 7/27/2022
Week 2, 8/03/2022
Week 4, 8/18/2022
Week 10, 9/29/2022
Week 11, 10/07/2022
Week 12, 10/19/2022
Week 21, 12/02/2022
Week 27, 1/25/2023
Week 33, 03/09/2023



Test Shaft
Friction (tsf)
Depth (ft)
Load Test
Uplift
Su non-inundated
(TAMU DST - PSI UU)
Su - Inundated
to -7.2 tsf
Reference Shaft
Friction (tsf)
Depth (ft)
Load Test
Uplift
Su - Non-inundated
(TAMU DST - PSI UU)
'Su - Inundated'
to -8.2 tsf