Enhancing Teaching of Foundation Design Theory with a Tension Pile Test

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Summary– ***The paper details a tension pile test conducted on the university campus as part of a Foundation Design course. The process included coordinating with the facilities office, drilling to a depth of 12 feet using a manual 4-inch auger, collecting soil samples every 3 feet for classification and capacity estimation, installing a ½-inch steel strand, pouring concrete, and applying tension with a hydraulic jack and reaction beam. The reaction beam, constructed from aluminum channels, was designed to transfer a 25-kip load from the jack to the strand without disturbing the surrounding soil.***

Students calculated the theoretical pile tensile capacity based on soil tests and compared it with experimental results, finding a strong correlation. Post-test observations revealed soil adhesion to the concrete pile, demonstrating the role of soil shear capacity in tension resistance. Conducted over two weeks, the project provided valuable hands-on experience, enhancing students' understanding of pile behavior under tension loads.

Key words—tensión pile, load test, foundations.

I. Introduction

The Foundation Design course offers students of Structural Analysis and Design Engineering Technology of the University of Houston Downtown (UHD) a comprehensive understanding of pile design, with emphasis on critical aspects such as cost efficiency, construction methods, and load capacities under both tension and compression. Recognizing the limited exposure students typically have to full-scale pile testing, Kershaw et al. [1] proposed the integration of lateral load testing into undergraduate curricula to bridge the gap between theoretical concepts and real-world behavior. In alignment with this approach, the present paper describes a hands-on pile testing project designed to provide practical insight into pile behavior under tensile forces. The project consists of several phases, including soil boring, pile construction, soil property analysis, load testing, and the preparation of a detailed final report.

II. Pile construction

The pile is constructed in a campus garden, following prior coordination with the University's Department of Facilities to ensure there are no conflicts with existing underground piles or electrical cables.

Students are divided into groups of four, with all groups participating in the boring process. Each group receives a soil sample for classification and testing, such as unconfined compression or direct shear tests, depending on the soil type. As depicted in Fig. 1a, the boring is conducted using a manual soil boring kit [2], capable of drilling a 12-ft deep, 4-in diameter hole. Soil samples are collected every 3 feet and distributed to student groups for laboratory analysis. A Standard Penetration Test (SPT) [3] is performed using the hammer included in the kit, as shown in Fig. 1b, which also aids in sample collection.

Upon completing the boring, a ½-inch grade 270 special strand with an anchor at the bottom is installed along the centerline of the pile before concrete pouring, as shown in Fig. 1c. The anchor is crucial to prevent strand slippage during the tension test.

Concrete is prepared using pre-mixed concrete bags from Quikrete, with water added according to the manufacturer's instructions [4] and plasticizer included to achieve a low-slump, highly workable mix. This mix allows the concrete to flow into the 4-inch borehole effectively, as illustrated in Fig. 1d. A concrete vibrator is used to ensure proper compaction.

Similar setup is described by Krishna and Murty [5] for field studies of the pull-out capacity of piles in expansive soils.

III. Tension pile test

The pile test is conducted one week after pile construction, allowing sufficient time for the concrete to gain strength. The tension test setup is based on the sketch shown in Fig. 2a. A 20-ton hollow hydraulic jack RCH-206 [6] is used to apply tension to the ½-inch special strand, with the jack force transferred to a reaction beam.

As detailed in Fig. 2b, the reaction beam measures 8 feet in length and is constructed using two aluminum 6061-T6 C8x3.75x1/4 channels, spaced ¾ inch apart to accommodate the strand. This design ensures efficient load transfer during the tension test.

The tension applied to the strand is transmitted to the concrete pile, which is supported by the soil through friction. The vertical movement of the pile is measured using a surveyor level and a ruler, as shown in Fig. 3.

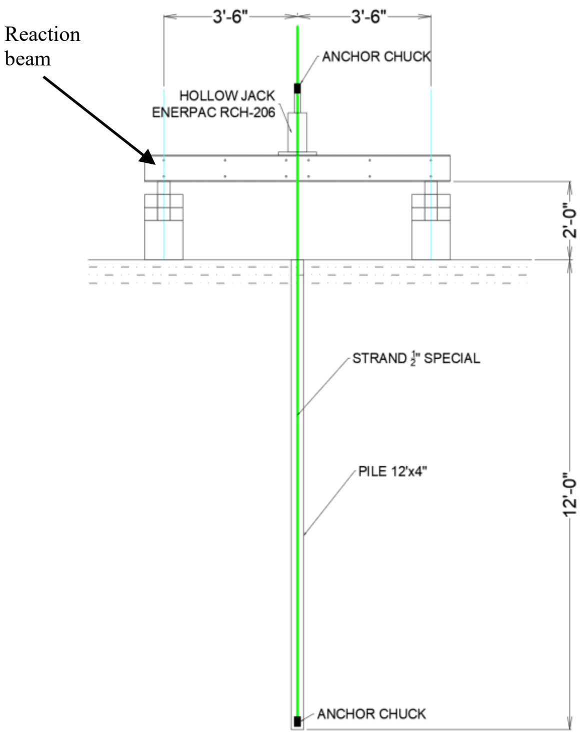
a. Use of the soil auger kit

b. SPT field test

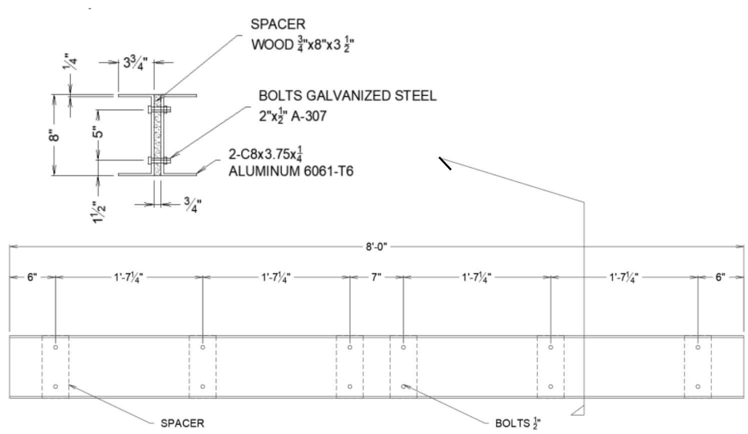
d. Strand ½” with end anchor chuck

c. Concrete pouring into boring

Fig.1 Construction of the pile



a. Sketch of tension pile setting



b. Reaction beam details

Fig. 2 Setup for the pile test

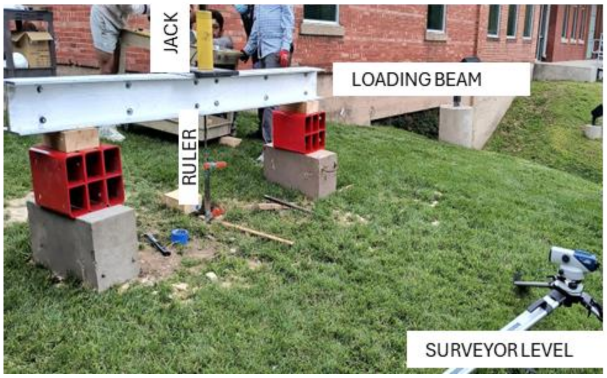


Fig. 3 Setting of tension pile test

a. End of test

b. Pile removed

c. Cross section

Fig. 5 Pile removed and transversal section after test

Fig. 4 presents load versus vertical displacement curves from three tension pile tests conducted in 2012, 2013, and 2024 in the same campus area. The maximum loads for these tests range from 20 to 23 kips, with all curves exhibiting similar patterns.

Initially, loads between 0 and 7 kips result in minimal displacements. From 7 kips to the peak load, the load-displacement relationship is linear. Beyond the peak load, the curves exhibit a behavior characterized by decreasing load and significant displacements. Unloading occurs when the jack piston reaches its maximum extension of 6 inches, at which point it is repositioned, and a new loading cycle begins.

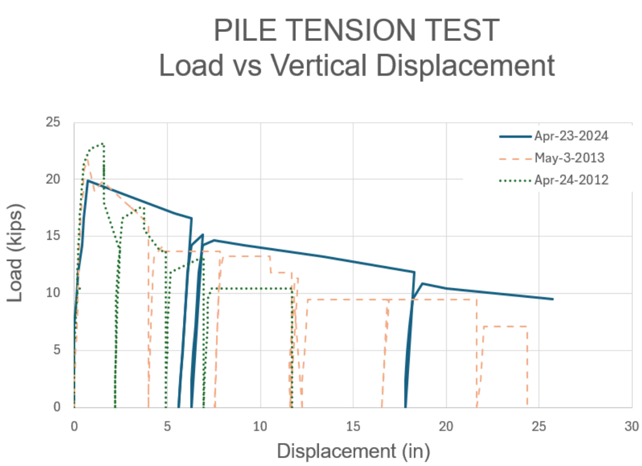


Fig. 4 Load vs displacement curve

The reloading phase exhibits linearity, with the peak load matching the value reached just before unloading. This pattern is consistent for subsequent loading cycles, including the third cycle. This trend demonstrates the pile's reduced capacity in re-loading cycles, indicative of permanent soil deformation and shear failure around the pile.

The test concluded when the pile moved approximately 2 feet, as the top of the pile contacted the underside of the reaction beam. To facilitate pile removal, the pile was broken into sections every 2 feet, as illustrated in Fig. 5a. The remaining segments were extracted using the hydraulic jack.

The pile was completely removed, as shown in Fig. 5b, to inspect for voids in the concrete that might have resulted from hole wall collapses during construction. No voids were observed in these tests. Fig. 5c reveals a thin layer of soil adhered to the pile, indicating the interaction between the soil and the concrete surface.

IV. THEORETICAL PILE CAPACITY IN TENSION

The following equation is used to compute the side friction capacity of piles in cohesive soils [7]:

$$Fs = Qs + Fs = \sigma'_x \cdot \tan\phi + \alpha.Su \quad (1)$$

Where:

$$Fs = \sigma'_x \cdot \tan\phi \quad (2)$$

$$Qs = \alpha.Su \quad (3)$$

σ'_x : horizontal effective stress = γ.h

γ: Soil density

h: Depth

ϕ: Angle of internal friction of the soil

α: Coefficient

$$0.5 <= \alpha = 1 - 0.5(Su - 500) / 1000 <= 1.0 \quad (4)$$

Su: undrained shear strength of the soil = c

$$T = Fs \cdot A \quad (5)$$

A: Area of the perimeter = π.Diam . L

Diam: Diameter of the pile = 4-in

L = Tributary length of each sample = 24-in

T : Theoretical tension capacity due friction of soil-soil

To estimate the pile capacity in tension, laboratory results of soil classification and shear strength are required. Tables I and II present the mechanical properties of soil samples collected every 2 feet during the years 2012 and 2013. Table III provides the soil classification for samples taken in 2024; however, due to time constraints, the mechanical properties for these samples were not determined.

The variations in soil classification and mechanical properties across the three borings are likely due to the site's history as a fill area, established approximately 80 years ago. This is evidenced by the discovery of artisan ceramic fragments within the soil.

TABLE I
LABORATORY RESULTS AND THEORETICAL CALCULATIONS OF THE TENSION CAPACITY (2012)

Diam = 4-in L = 24-in A=301.6 in^2 = 2.09 ft^2

Depth h (ft)	Classification		Friction ϕ	Cohesion, c (psf)	α	Density, γ (pcf)	Ti = Qs+Ff (lb)
1	CL	Lean clay	8	4103	0.5	124	4333
3	CL	Lean clay	8	6817	0.5	132	7255
5	CL	Lean clay	8	6817	0.5	132	7333
7	ML	Silty clay	10	3838	0.5	99	4275
9	ML	Silty clay	22	1619	0.5	113	2556
11	ML	Silty clay	34	0	1.0	98	1523

T = ΣTi = 27275 lbs

TABLE II
LABORATORY RESULTS AND THEORETICAL CALCULATIONS OF THE TENSION CAPACITY (2013)

Diam = 4-in L = 24-in A=301.6 in^2 = 2.09 ft^2

Depth h (ft)	Classification		Friction ϕ	Cohesion, c (psf)	α	Density γ (pcf)	Ti= Qs+Ff (lb)
1	ML	Silty clay		0	0.5	95	0
3	ML	Silty clay	8	4100	0.5	98	4313
5	ML	Silty clay	8	4500	0.5	111	4734
7	ML	Silty clay	10	4600	0.5	121	4842
9	CL	Lean clay	22	4300	0.5	132	4537
11	CL	Lean clay	34	1600	1.0	132	3360

T = ΣTi = 21812 lbs

TABLE III
LABORATORY RESULTS AND THEORETICAL CALCULATIONS OF THE TENSION CAPACITY (2013)

Diam = 4-in L = 48-in

Depth, h (ft)	Classification	
4	CL	Lean clay
8	CL	Lean clay
12	CL	Lean clay

Table IV compares the theoretical tension capacity with the maximum load observed during the tests. The ratio of the test results to the theoretical capacity ranged from 0.85 to 0.95, which aligns with values reported in the literature [8].

TABLE IV
COMPARISON OF THE TENSION CAPACITY BETWEEN THEORETICAL AND TEST RESULTS

Pile 12-ft long, 4-in diameter

Test	Theoretical (kips)	Tension Test (kips)	Test/Theory (%)
2012	27	23	0.85
2013	22	21	0.95
2024		20	n/a

Figure 5c shows a thin layer of soil adhered to the concrete surface, indicating that failure occurred as the soil reached its maximum shear strength before full mobilization of friction at the soil–concrete interface, behavior typically observed in cohesive soils interacting with concrete. In such cases, adhesion between soil particles and the concrete surface leads to interface failure prior to the full development of frictional resistance, as reported by Li et al. [9] and Zhou et al. [10].

V. ACADEMIC ASSESSMENT OF THE PROJECT

This project integrates knowledge from Soil Mechanics and Foundation Design courses with hands-on fieldwork, including drilling, concrete pouring, equipment setup for testing, and the application of loading-unloading cycles. Students also prepared a detailed report, combining practical experience with engineering analysis. The outcomes of the project were showcased in a student conference via a poster presentation.

Overall, the project demonstrated high student engagement and interest, providing valuable real-world experience permitting the application of their teamwork skills.

During the final week of each semester, students submit a portfolio reflecting on their learning throughout the course. When the pile test is included, over 90% of students indicate in their reflections that the hands-on experience significantly enhanced their understanding of pile behavior under tension.

However, due to the substantial time commitment required to complete all project tasks, it is advisable to initiate the project at least one month before the end of the semester. Additionally, as this type of project is weather-dependent, all activities should be scheduled with caution, and work should be avoided during potential storm conditions to ensure safety.

VI. CONCLUSIONS

Student engagement was strong, with active and enthusiastic participation throughout all stages of the project. Careful planning was essential to achieving the project's objectives within the course's time frame. The load–displacement curves from the three tension pile tests conducted in the same campus area exhibited similar behavior and showed good agreement with theoretical predictions. The tension testing setup demonstrated versatility and can be adapted for different soil types. Future work may involve testing additional pile types, such as helical piles, compacted gravel piles, and underreamed piles. The setup can also be modified to perform compression tests on small shallow foundations.

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