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EVALUATION OF PILE TENSION LOADS USING PULL-OUT AND PUSH-OUT METHODS

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A R T I C L E I N F O

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A B S T R A C T

Strain gauge instrumented static tension load testing in bored piles can give the designers a variety of useful information based on the geotechnical conditions. Traditional tension or uplift tests are performed using the pull-out method, which is sometimes inappropriate economically and technically. For the past few decades, Bidirectional Static Load Testing method (BDSLT, commonly known as the O-cell method) has been proven advantageous over the conventional pile load testing method for compression piles. However, the application of BDSLT in tension load tests (push-out), an alternative to the traditional method (pull-out), is seeking wide acceptance in the construction industry. This push-out method provides the facility to install sacrificial jacks within the toe level of the pile and extend an additional reaction pile below the design toe level. In this article, a comparison of the upward behavior of the shaft using instrumented pull-out and push-out methods is studied. The piles of 900mm diameter, 6.0m length were instrumented with 4 levels of vibrating wire strain gauges and tested up to 5000kN for a high-rise building project in Qatar. The maximum settlement observed was 4.60 mm for the pull-out test and 4.20 mm for the push-out test, respectively. The unit shaft friction shows a maximum of 312 kPa for the pull-out test and 395 kPa for the push-out test, indicating that the outcomes are fairly similar. The results of this study suggest that push-out tests can be used as an innovative alternative to conventional technique to bring economic and project executional benefits.

Introduction:

Some of the foundations are designed with tensile piles, depending on the suitability of the ground conditions. It is generally accepted that pull-out tests are not very common in deep foundation projects as the 70% compression load is assumed as the tension capacity. However, there are still limitations to predicting the upward capacity of a compression pile without performing an instrumented load test. There are a lot of challenges associated with the execution of a traditional pull-out test on site, especially with higher test loads. The shaft resistance of tension test bored piles has been studied by various researchers [1, 2]. The upward or downward direction of the load movement has no effect on the shaft resistance, and hence the shaft shear stress absolute values are the same in both tests [3, 4]. Fields and Bischoff [5] acknowledged the tensile stress behavior along the reinforced concrete bored piles.

Early in the 1980s, in Brazil, and about ten years later, in the USA, the first Bidirectional Static Load Test (BDSLT) was conducted [6, 7]. BDSLT has been extensively used in the Middle East for the past twenty years in a variety of non-working piles, working piles, and rectangular deep barrettes to verify the initial design and conduct additional value engineering [8, 9, 10]. This static load test technique is referred to in a number of international standards [11, 12, 13]. With the introduction of BDSLT for tension testing (push-out), a replacement for the conventional pull-out test, it is now gaining widespread acceptance in the foundation industry. The novel approaches offered by embedding a sacrificial loading jack within a test pile are described in this paper. This includes the installation of a reaction pile beneath the test pile at a deeper depth at the same time as the test pile. Even though there are numerous studies related to compression tests using the BDSLT method, very limited information is available about the comparison of strain gauge-instrumented pushout and pullout tests under the same geotechnical conditions. This study aims to compare the results from both methods during upward loading to help future infrastructure projects.

Subsurface Geology:

The proposed study area is located in Doha Corniche, Qatar. The general subsurface ground condition consists of yellowish brown silty/clayey gravelly sand up to -1.90 m QNHD (meter Qatar National Height Data). The above is followed by very weak to weak Simsima Limestone, which was observed up to -23.40 mQNHD. The Midra Shale, which consists of extremely weak to weak, grey to brown Claystone interlayered with very weak to weak, off-white to light brown limestone, was identified up to -27.40 mQNHD. Below this depth up to the end of the borehole (-42.40 mQNHD), the Rus Formation consists of extremely weak to weak, off-white to light brown /grey Calcisiltite and Calcarenite, was encountered. The table (Table 1) shows the general soil and rock description with recommended design parameters.

Elevation (mQNHD)		**Layer description**	**Skin friction (kPa) (q_s)**	**End bearing (kPa) (q_b)**
2.60	-1.90	Silty/clayey gravelly Sand	-	-
-1.90	-23.40	Simsima Limestone	600	500
-23.40	-27.40	Midra Shale	200	50
-27.40	-42.40	Rus Formation	450	250

Table 1. General subsurface details

Methodology:

The distribution of side shear resistance along the shaft and the axial load imparted to a deep foundation can both be determined using instrumented tension or uplift field pile tests. The test set up was carried out as per the procedures described in ASTM D 3689 [14]. Generally, test piles are instrumented with load cells, jacks, vibrating wire strain gauges (4 levels x 4 nos. = 16 nos.), and displacement transducers. Because of safety concerns, the test frames must be designed, approved, and incorporated with the above electronic devices with an automatic data logging system, and the data will be analysed to obtain the required load and settlement parameters. (Fig 1).

Fig.1. Traditional pull-out test set up

BDSLT (push out) is performed as per ASTM D 8169-18, using a sacrificial hydraulic jack assembly embedded at the toe level of the pile foundation element. In this test, the jack assembly consists of two 2500 kN bidirectional hydraulic jacks located between upper and lower bearing plates (Fig. 2). Four levels of vibrating wire concrete embedment-type strain gauges, comprising four units at each level, were utilized to understand the pile shaft resistance behavior. As the end bearing reaction is not sufficient in most of the Middle East ground conditions to overcome the shaft friction of the test pile, an additional length of the same pile can be constructed and installed at the same time. There is no need to extend the pile up to working platform level, as followed for traditional pull-out tests, and it can be discontinued 0.50m to 1.0m above the cutoff level to avoid any additional weight and resistance errors.

The additional pile length required below the deign toe level is calculated using the following equation 1.

$$L = P/(q_s*rf*\pi*D) \quad (1)$$

Where: L - pile length
P - test load
q_s - shaft friction
rf - resistance factor (varies, but is generally used as 0.80)
π - pi
D - pile diameter

The loads are applied from a hydraulic pressure system to the foundation in an upward and downward direction. The upward jack movement, load, and strain readings are measured during the load application (Fig.3). The test was performed on two preliminary test piles, namely PL1 (pull out) and PS1 (push out), and the details are provided in Table 2.

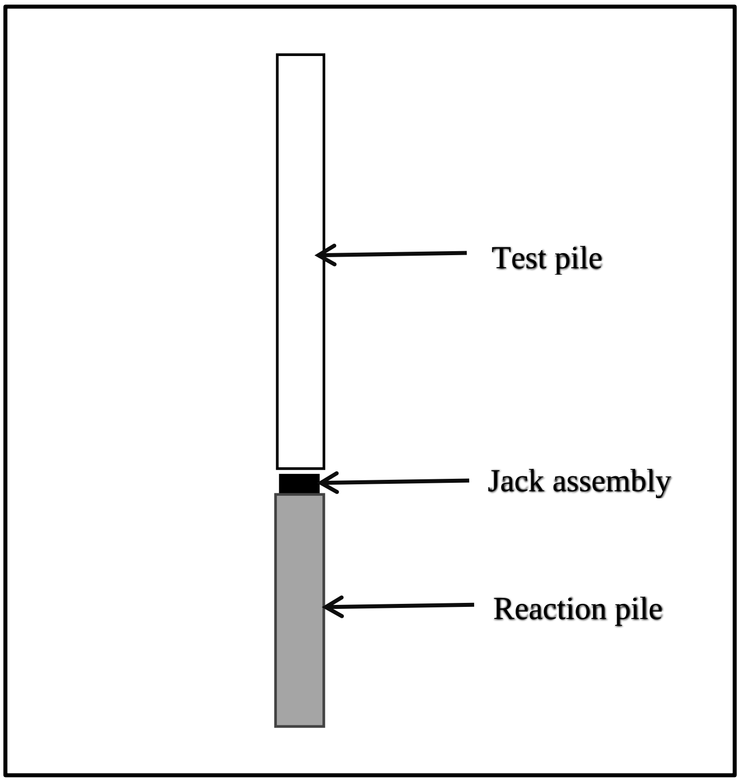

Fig.2. Typical push-out test diagram

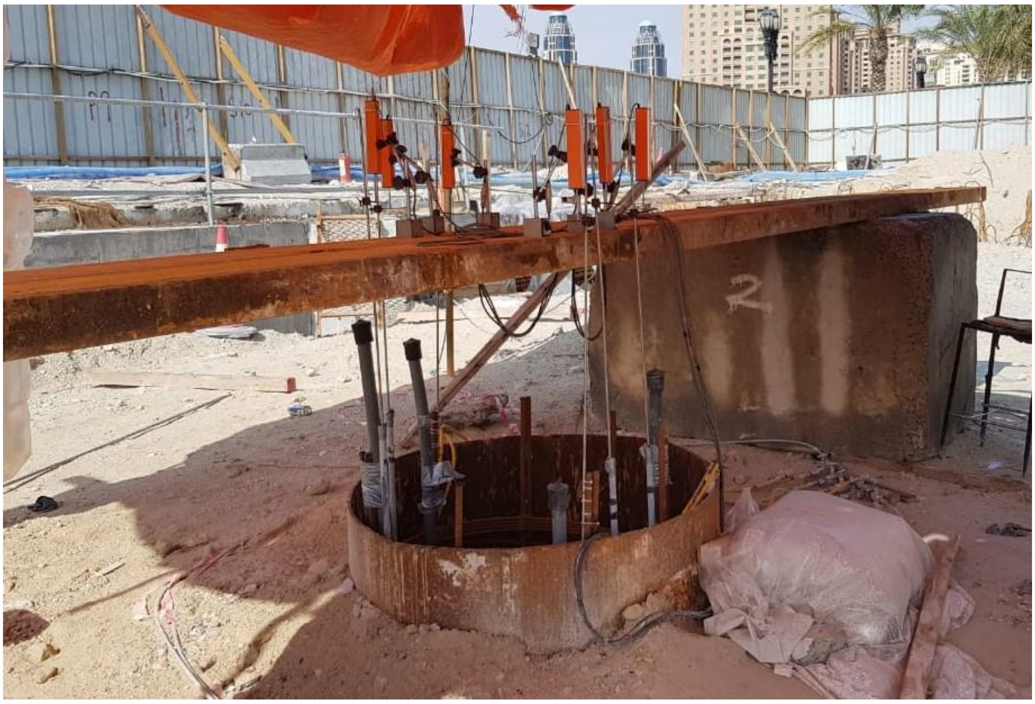

Fig.3. Pull-out test set up using BDSLT

Pile ID	Diameter (mm)	Platform level (m QNHD)	Cutoff level (m QNHD)	Toe level (m QNHD)	Working load (kN)	Test load (kN)	Strain gauge levels (m QNHD)
PL1 (pull out)	900	-9.00	-10.55	-16.55	2500	5000	-11.00, 12.50, -14.00 and -15.50
PS1 (push out)	900	-10.00	-10.55	-16.55	2500	5000	-11.00, 12.50, -14.00 and -15.50, Jack top level at -16.55 and reaction pile tip at -20.25

Table 2. Details of the preliminary test piles

Results and discussion:

The settlement displacement data obtained from the pull-out and push-out tests are presented in Table 3. In the push-out test, the upper movement is governed by shaft resistance developed in the foundation upper portion, and the movement data obtained from this section was directly used as the displacement value.

Applied Load (kN- kilo Newton)	Applied load (%)	Settlement (PL1)	Settlement (PS1)
0	0	0.00	0.00
1250	50	0.50	0.45
2500	100	1.30	1.10
5000	150	4.60	4.20

Table 3. Load -Settlement values

In both test methods, the loading test continued until 200% of the load and did not show any evidence of failure of the piles. The settlement obtained from the pull-out test at ultimate load was 4.60 mm, and that from the push-out test was 4.20 mm. The slightly higher value during the pull-out test was due to the elongation of the reinforced concrete pile casted above the design cutoff level. The unit shaft friction distribution was calculated using the strain gauge data obtained from the pile segments during the load tests at the ultimate test load (Table 4).

Strain gauge level (m QNHD)	Unit shaft friction (kPa – kilo Pascal)	
	PL1	PS1
-11.00 to -12.50	235	153
-12.50 to -14.00	312	296
-14.00 to -15.50	185	395

Table 4. Unit shaft friction obtained at test load from pull-out and push-out tests

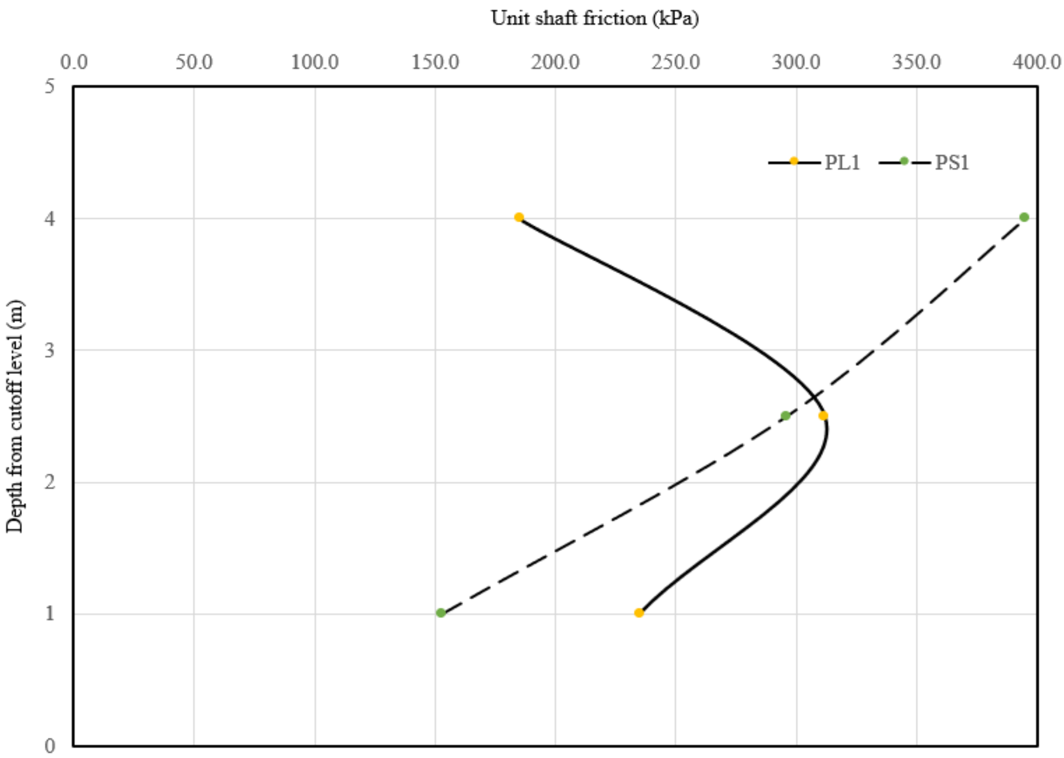

Fig.4. Unit shaft friction of PL1 and PS1

The maximum average shaft resistance mobilized from PL1 (pull-out test) ranged from 185 to 312 kPa, and from PS1 (push -out test), it was 153 to 395 kPa at the test load. The variation in unit shaft friction from both tests was due to the load transfer behavior at the pile-soil interface, the development of steel-concrete bond stress along the pile shaft concrete, and the location of load application (Fig.4). For PL1, the layer close to the pile top and middle segments resists the uplift load and prevents it from being effectively transmitted to the pile bottom segment. On the other hand, PS1 makes good use of the properties and thickness of the layers at the pile's bottom section, which can offer more lateral resistance and can resist the weight of the upper stratum. This eventually aids in the soil layers at the bottom of the pile exerting lateral friction and can compensate for any slight lateral friction at or near the pile's top.

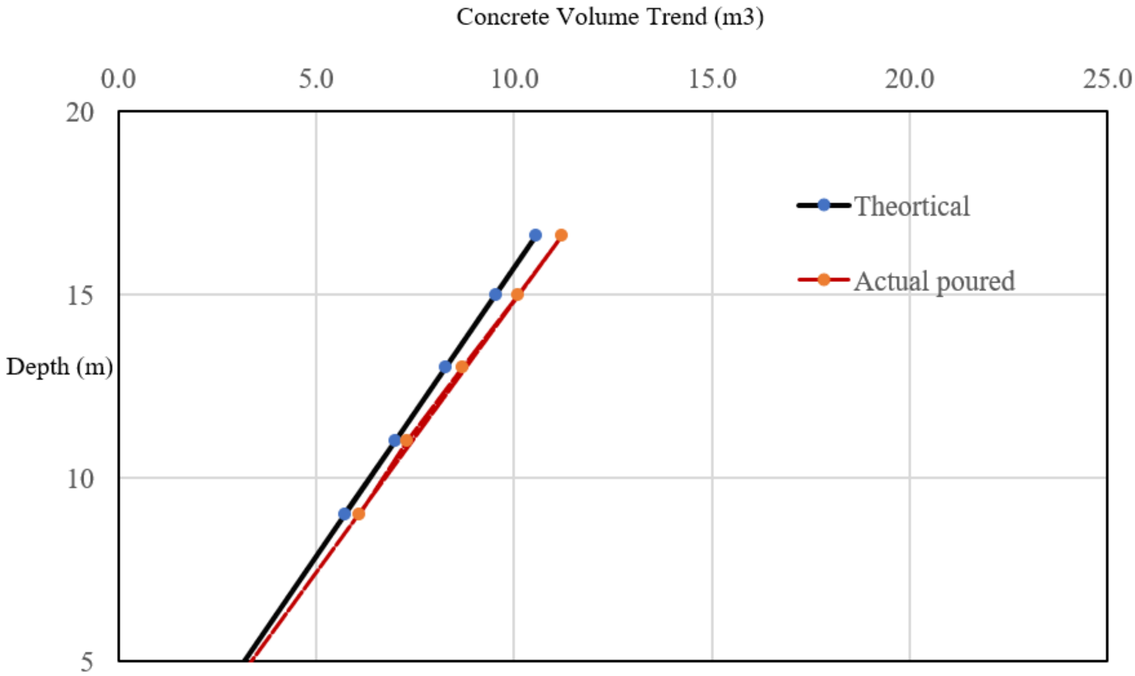

Fig. 5. Concrete voulme trend comparison for PL1

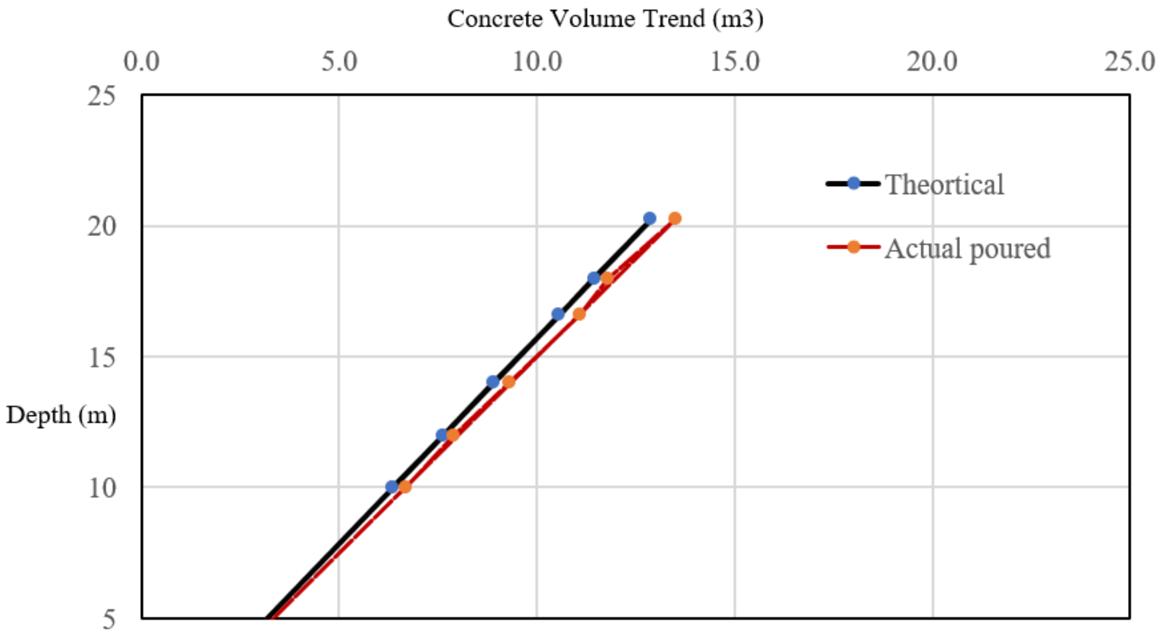

Fig. 6. Concrete voulme trend comparison for PS1

The theoretical and actual concrete volume trend for PL1 and PS1 shows a variation of less than 10%, which is insignificant (Fig.5 and Fig. 6). In relatively uniform piles, the Poisson's ratio effect, which is simply defined as the change in the pile's cross section during the application of compression or tension loads, can be discarded. This is because the reinforced concrete pile's stiffness is relatively high, and hence the consequences of a change in section brought on by compression or tension are insignificant [3]. The piles are tested in stiff layers, so there won't be any changes to the diameter of the piles or any tendency for the pile-soil interface to become compacted due to the Poisson effect of the pile body for PL1 and PS1.The smaller settlement values, PL1 showing 4.60 mm and PS1 showing 4.20 mm, make this explicit, as the amount of elongation and compression of the pile body is nominal. For longer steel tubular piles with significant residual loads, the Poisson's ratio effect must be taken into account. Poisson's ratio effect causes a significant shear stress deviation below the half-length and close to the pile's tip, where the bending moment is minimum. There-fore, the push-out method can also be used in the working tension pile tests as long as the load is applied at the design toe level.

The results of both load tests accurately reflect the characteristics of the soil strata when combined with pertinent information about pile design. It is confirmed by the analysis that both test methods are practically accurate enough to predict the pile's uplift behavior. The push-out test is thus identified as a viable alternative to the traditional pull-out test for determining the ultimate tensile capacity of deep foundations. However, differences in results may arise in terms of pile construction defects such as irregularity of bored piles, excessive construction time, degradation of shaft capacity due to drilling fluids, etc, and hence proper construction quality checks are necessary to minimize the errors and overall foundation risk.

When the desired final cut-off level of the pile is below the test platform, as in the test under discussion, pull-out tests become even more challenging for the steel connecting the test pile to the reaction beam, as complex friction reduction sleeves may be needed. It is considerably difficult to guarantee that the tension test setup delivers a precisely axial tension load if the top of the concrete of the test pile is left below or above the test platform level. As a result, the test pile may experience more resistance, and lateral forces acting on the response system may jeopardize its stability and safety. In contrast, the loading element is cast inside the test pile when using the push-out method. Since no reaction beams are needed at ground level, both the test's footprint and the risks associated with expensive reaction beams are greatly reduced.

Conclusion:

In the same geotechnical conditions, instrumented pull-out and push-out tests were compared, and the findings are presented in this paper. This pilot study confirms that both approaches are virtually accurate enough to estimate the pile design parameters. It has been demonstrated that uplift load tests in stiff layers are not influenced by pile geometry. When compared to the conventional pull-out test, the push-out test has a number of benefits in terms of testing, deployment, speed, safety, cost, and the interpretation of test findings. Additionally, push-out testing using sacrificial hydraulic jacks is a novel engineering technology that can be used without any external loading mechanism. Similar comparative studies in different pile geometry and geotechnical conditions will add value to the current inferences.

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