Bidirectional load test in HoChiMinh City: a case history and lessons learned

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Bidirectional load test in HoChiMinh City: a case history and lessons learned

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Abstract. Bidirectional static load tests to evaluate the axial load-bearing capacity of large cross-sectional bored piles are indispensable. Nonetheless, this test is complicated, costly, and easy to fail. A case history of a bidirectional static load test conducted in HoChiMinh City is reported and analyzed. In particular, a bored pile with 1.8m in diameter and ~60m in embedment length, located in Tan Binh district, HoChiMinh City, is tested using the bidirectional static load test. The testing load is close to 48MN. The state-of-the-art methods to analyze the data of bidirectional load tests such as back-calculation, constructing equivalent load-displacement curve as head-down static load test, will be adopted then the lessons learned from the case history are elucidated. A guideline to carry out a bidirectional load test is presented. In essence, this study could facilitate the success of bidirectional load tests conducted on large cross-section bored piles.

1. Introduction

HoChiMinh City has seen an increase in several high-rise buildings and long-span bridges, requiring large diameter bored piles or barrette piles. Due to the complex soil profile and super long piles, the design requires reference to full-scale static loading tests. Considering the huge costs of an external reaction system and the necessity of large maximum test loads, bi-directional static loading tests [1] were often used.

The bidirectional static load test is a method to determine the capacity of piles under both compression and tension loading. Dr. Jorj Osterberg established Loadtest Inc. in the late 1980s to further develop and promote the technique. The company has since made significant contributions through the use of strain-gage instrumentation. The test is used to determine the pile's overall capacity and behavior under load, and with high accuracy and precision in measuring load and deformation. The bidirectional static load test has been widely accepted by experts as the most effective method for simulating in-service conditions for deep foundation elements. While these full-scale tests can be costly to execute, they are a necessary investment to properly evaluate the results. Instrumentation with strain gages is used to measure load distribution during the test, and proper installation and interpretation of these gages are crucial to ensure the accuracy and effectiveness of the test results [2].

Converting strain measurements to load using the pile secant stiffness and the tangent stiffness method is an important method to determine the load on a pile during both compression and tension loading in bidirectional load testing [3]. The pile secant stiffness method measures the strain at several points along the pile and calculates the slope of the load-strain relationship to determine the load, while the tangent stiffness method measures the strain at a single point along the pile and calculates the slope of the load-strain relationship at that point [4], [5]. Both methods allow for high accuracy and precision in the measurement of load and deformation and are useful for determining the capacity of piles and designing the foundation of a structure [6]. Accurately determining the pile stiffness is crucial for the analysis of the load-bearing behavior of bored piles, since the pile stiffness is no longer linear but potentially non-linear [7]. A critical assessment on the determination of pile modulus has also been conducted by Lam and Jefferis [8]. These methods are employed in this study.

An effective stress back analysis is an important step to evaluate the capacity of piles from the result of static loading tests [9]. This method uses the measured strains and soil properties to calculate the effective stresses at various points within the soil and estimate the pile's capacity. This method is particularly useful for bidirectional or conventional head-down loading tests as it allows for a more accurate determination of the pile's capacity by evaluating the soil's response under both compression and tension loading conditions. Furthermore, the effective stress back analysis could facilitate the inspection of pile behavior subjected to long-term conditions. Using UniPile [10], a commercially available software (www.unisoftGS.com), effective stress back analysis is employed to advance the load-displacement behavior of the bored piles.

The objectives of this study are: (i) to present a case study on conducting a bidirectional static load test, with a maximum load of approximately 48 MN; (ii) To utilize state-of-the-art analysis techniques on collected data to investigate the load-displacement behavior of piles.

2. Materials and methods

2.1. Soil profiles

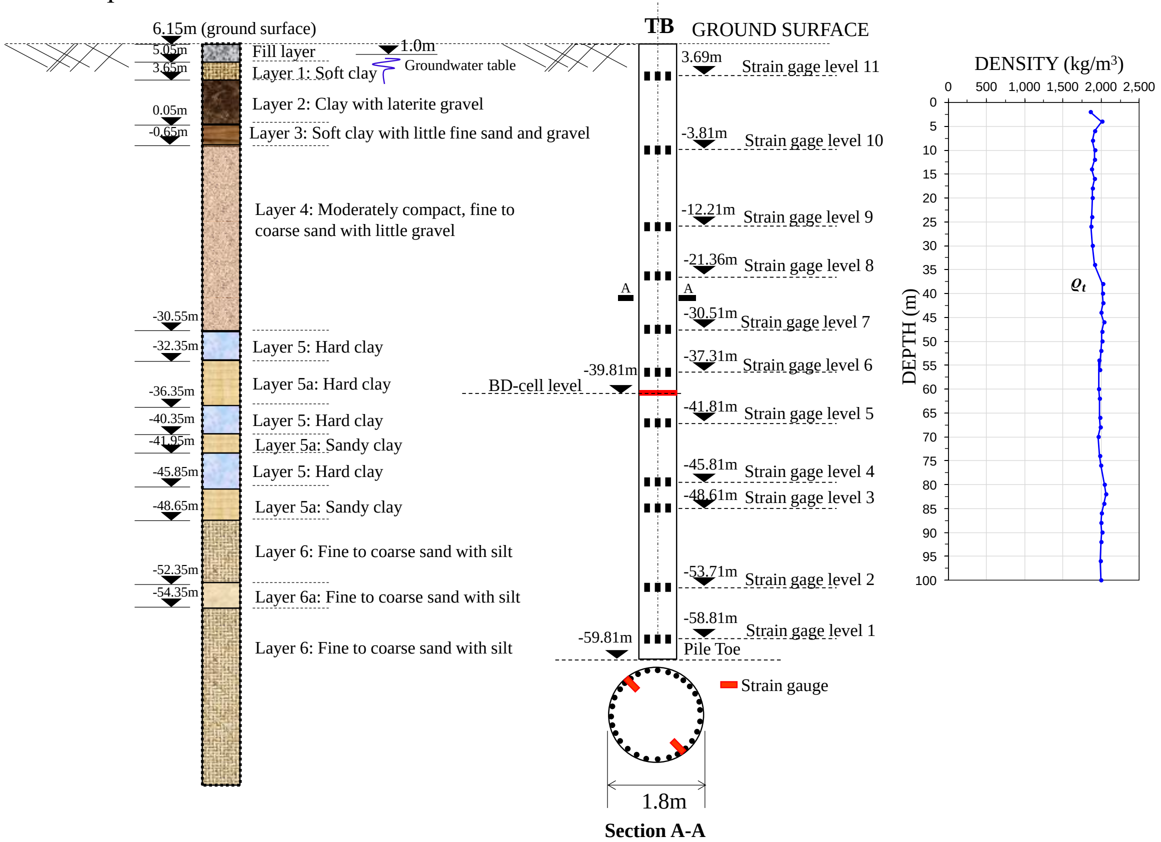

Figure 1. Soil layers, pile embedment along with strain gage instrumentation, and variation of density with depth.

Table 1. Summary of soil parameters from laboratory tests.

Soil layers	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5a	Layer 5	Layer 6
Description	Soft CLAY	CLAY with laterite gravel	Soft CLAY with little fine sand and gravel	Moderately compact, fine to coarse SAND with little gravel	Hard CLAY	Sandy CLAY	Fine to coarse SAND with silt
Thickness [m]	0.50-1.10	2.20-5.10	0.70-2.90	29.20-30.30	10.00-13.70	1.80-6.20	24.10-27.6
Color and State	yellow-gray, soft plastic state	red-brown yellow-gray, hard plastic state	gray-yellow brown-red, soft plastic state.	brown-red gray-white, brown-red, the texture is semi-tight	red-brown with dapple of yellow, yellow-brown, hard state.	brown-yellow with dapple of blue-gray, semi-hard state.	yellow-red-brown, textures is tight.
ϕ_{UU} [degrees]	5°50'	-	10°35'	28°29'	16°09'	12°46'	-
c_{UU} [kPa]	32		20.8	4.3	53.3	41.8	-
ϕ_{CU} [degrees]	12°16'		-	-	-	18°13'	-
c_{CU} [kPa]	33.2	-	-	-	-	50.5	-
ϕ_{CD} [degrees]	23°17'	-	-	33°30'	20°59'	25°33'	-
c_{CD} [kPa]	20.3	-	-	8.9	47.1	37.0	-
Permeability coefficient [m/s]	5.46 x 10^{-7}	4.63 x 10^{-7}	-	1.15 x 10^{-5}	-	-	-
Unconfined compressive strength [kPa]	-	110.4	77.1	-	-	-	-
N-SPT [blows/0.3m]	6	6-27	5-7	8-29	30-47	19-29	30-59
$av_{100-200}$ [m^2/kN]			0.00018	0.00030			
$av_{200-400}$ [m^2/kN]			0.00009	0.00016	0.00006	0.00009	
$av_{400-800}$ [m^2/kN]					0.00003	0.00005	0.00006
$av_{800-1600}$ [m^2/kN]							0.00003
$av_{1600-3200}$ [m^2/kN]							
$E_{100-200}$ [kPa]			3804.0	4400.1			
$E_{200-400}$ [kPa]			7924.2	8420.8	11370.5	9690.4	
$E_{400-800}$ [kPa]					22308.8	19189.9	22606.3
$E_{800-1600}$ [kPa]							43797.8
$E_{1600-3200}$ [kPa]							

UU: Unconsolidated-Undrained, CU: Consolidated-Undrained, CD: Consolidated-Drained

The bored pile is embedded in the ground with soil profiles given in Table 1. In general, the subsurface condition is favorable for pile foundation as the sandy soil appears in various layers. The pile toe is embedded in layer 6 which is fine to coarse sand with SPT indexes varied from 30-59 blows (see Figure 1).

2.2. Test schedule

The test is conducted in two cycles of loading-unloading-reloading according to Vietnam standards (ref. Figure 2). It should be noted that this loading-unloading-reloading undermined the value of the testing data. In other words, the obtained data are somewhat unreliable under this testing schedule. The upper part of the pile above the load cell has considerably moved upward under the testing load whereas the movement of the lower part is insignificant, i.e., 10mm (see Figure 3). This signifies that the location of the BD cell has not been reasonably estimated.

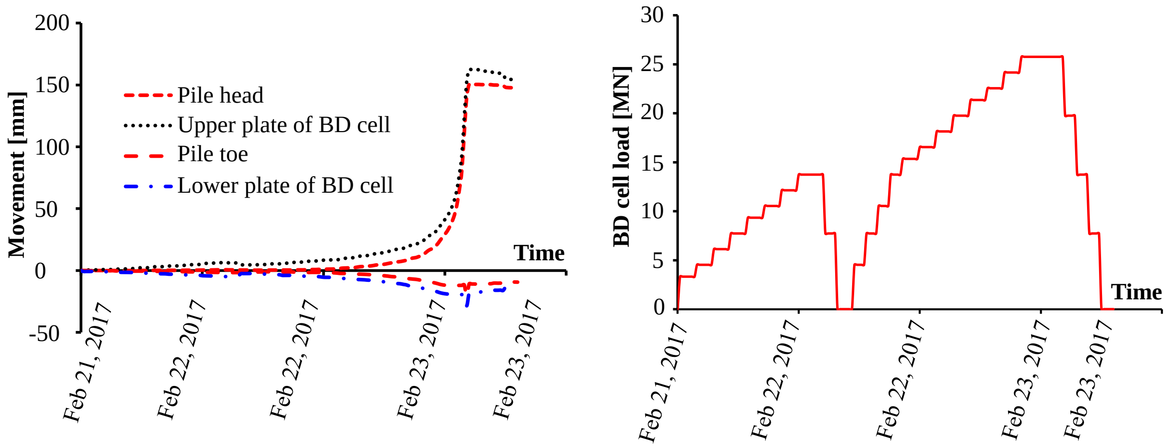

Figure 2. The loading steps and BD-cell movements during the testing process.

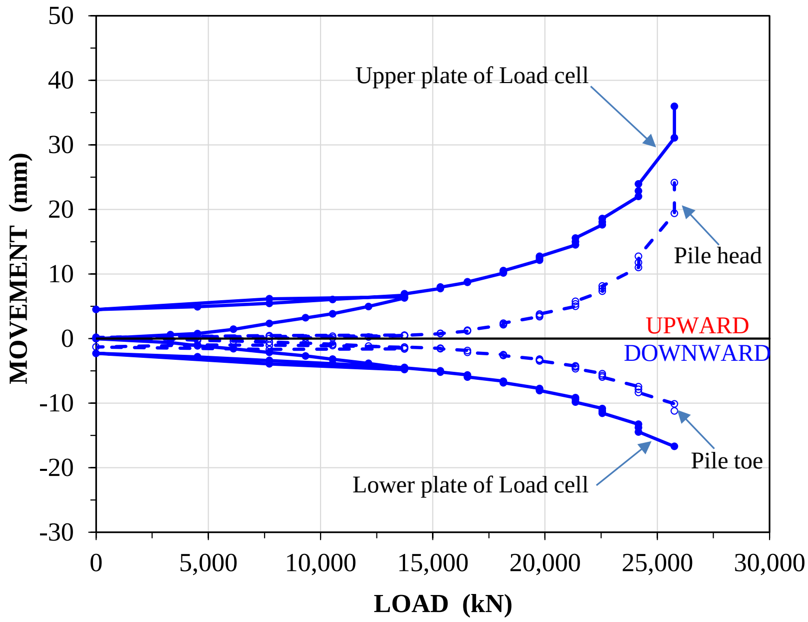

Figure 3. Load-displacement of bidirectional pile loading test.

3. Results and discussion

To start running the analysis of BD load test data, the strain reading from the set of strain gages instrumented in the pile needs to be examined as the faulty reading data of the strain gage could deviate from the output unexpectedly. If any faulty reading data were detected, they were then excluded to avoid excessive error via taking the average value of the erroneous data.

After examining the accuracy and reliability of the strain gage reading, the pile's stiffness needs to be determined. The secant stiffness and the tangent stiffness were determined as shown in Figure 4 and Figure 5, respectively. The value of the pile's stiffness is determined thereof, i.e., EA=70GN. The accuracy of the obtained pile's stiffness is crucial for achieving a meaningful outcome of the analysis. Unfortunately, most of the strain data reading from the gage is not reliable. Thus, more effort is needed to digest the testing data for evaluating the reliability of the design. Furthermore, the unloading-reloading phase and the varying load-holding duration have made even the surviving strain-gage measurements less useful (ref. Figure 5).

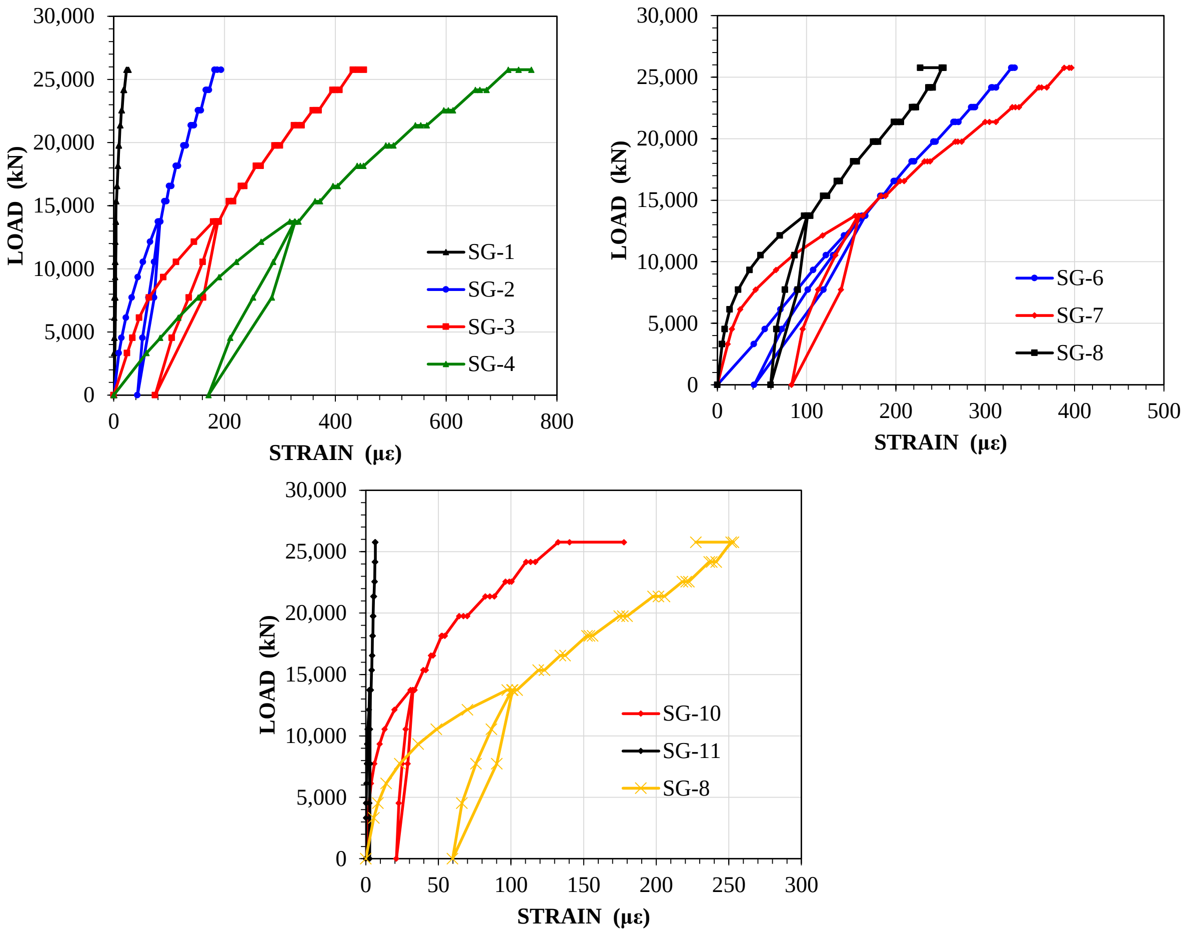

Figure 4. Load-strain reading from the set of strain gages.

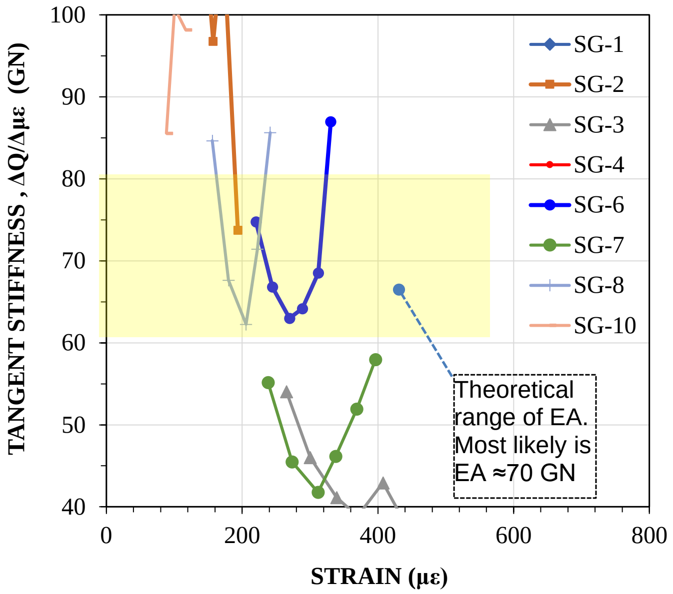

Figure 5. Tangent stiffness.

The obtained pile stiffness is fed into the *UniPile* software to conduct a back-calculation of the BD static load test (see Figure 6). The back-calculation is based on the effective stress analysis method (β-method). The result of the back-calculation is provided in Table 2.

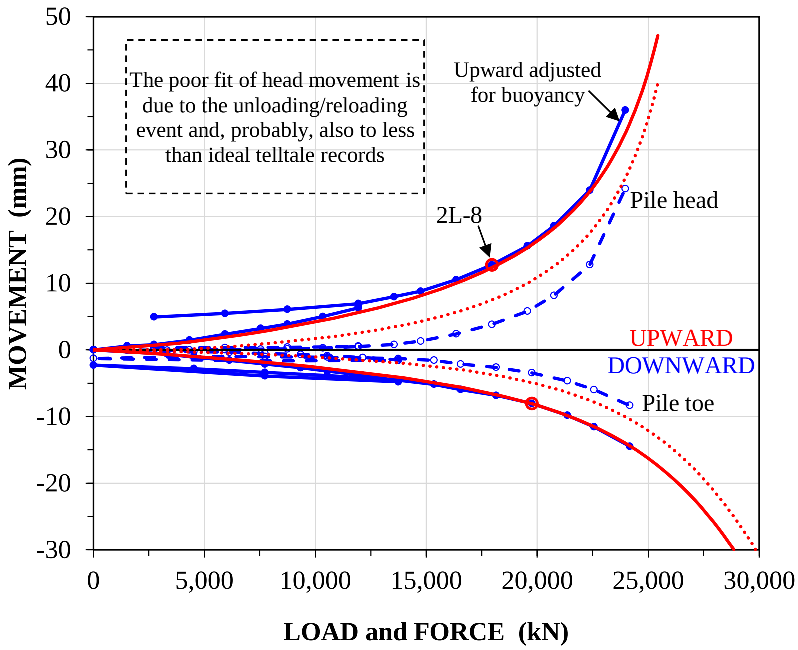

Figure 6. Measured and simulated load-movement curves.

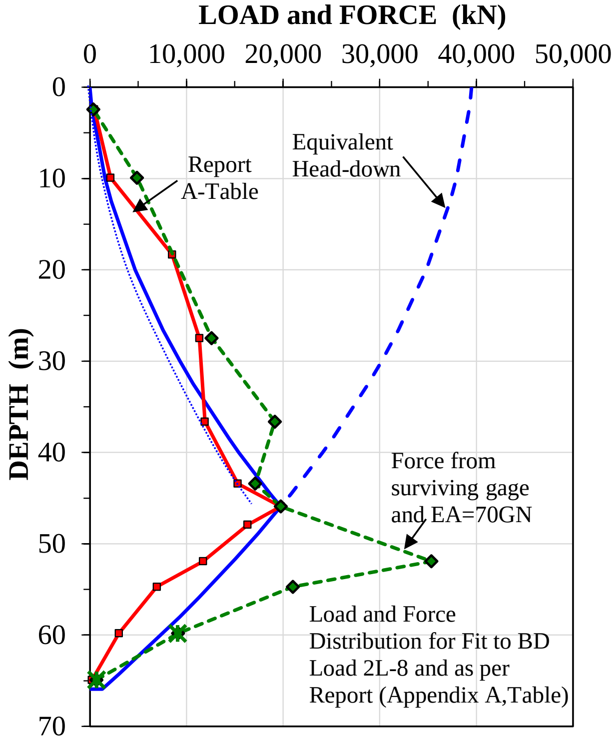

Figure 7. Load and force distribution along the depth.

As mentioned above, including a faulty reading of the strain gage could cause an erroneous outcome. Figure 7 demonstrates the load and force distribution along the embedment length of the pile. The red solid line is the outcome including a faulty reading of the strain gage while the blue solid line is the outcome from which the faulty reading on the strain gage had been excluded. The discrepancy is considerable. It should be noted that the strain-gage records are not useful for determining force distribution.

Table 2. The result of back-calculation.

Pile TB at Initial Condition: Static							
	Effective	Load		Resistance		Equivalent	
Depth (m)	Stress (kPa)	Q_n (kN)	Q_d+Q_n (kN)	R_s (kN)	R_u-R_s (kN)	r_s (kPa)	Beta, *ß*
Layer 1 (clay): 0 - 6.0 m							
0	0	0	0	0	37,666	0	0.25
2	36	51	51	51	37,615	9	0.25
4	52	175	175	175	37,490	13	0.25
6	68	345	345	345	37,321	17	0.25
Layer 2 (sand): 6.0 - 36.6 m							
6	68	345	345	345	37,321	22	0.32
9.9	107	963	963	963	36,703	34	0.32
21	218	4,226	4,226	4,226	33,439	70	0.32
27.5	283	7,173	7,173	7,173	30,493	91	0.32
36	368	12,180	12,180	12,180	25,486	118	0.32
36.6	374	12,582	12,582	12,582	25,083	120	0.32
Layer 3 (clay): 36.6 - 45.9 m							

36.6	374	12,582	12,582	12,582	25,083	94	0.25
43.2	427	16,318	16,318	16,318	21,347	107	0.25
43.6	430	16,561	16,561	16,561	21,105	108	0.25
45.22	443	17,558	17,558	17,558	20,108	111	0.25
45.9	448	17,913	17,913	17,989	19,677	112	0.25
Layer 4 (clay): 45.9 - 54.8 m							
45.9	448	17,913	17,913	17,989	19,677	112	0.25
47.22	459	18,184	18,184	18,833	18,833	115	0.25
47.22	459	18,184	18,184	18,833	18,833	115	0.25
49.37	476	17,412	17,412	20,254	17,412	119	0.25
51.9	496	15,670	15,670	21,996	15,670	124	0.25
52.9	504	14,963	14,963	22,703	14,963	126	0.25
54.7	519	13,661	13,661	24,005	13,661	130	0.25
54.8	520	13,587	13,587	24,078	13,587	130	0.25
Layer 5 (sand): 54.8 - 59.8 m							
54.8	520	13,587	13,587	24,078	13,587	166	0.32
58	552	10,486	10,486	27,180	10,486	177	0.32
59.8	570	8,660	8,660	29,006	8,660	182	0.32
62.5	597	5,811	5,811	31,855	5,811	191	0.32
Layer 6 (sand): 59.8 - 65.0 m							
62.5	597	5,811	5,811	31,855	5,811	191	0.32
65	622	3,055	3,055	34,610	3,055	199	0.32
65.9	631	2,036	2,036	35,630	2,036	202	0.32

Owing to the merit of effective stress back analysis, the equivalent head-down test has been achieved by applying the *t-z* and *q-z* functions obtained from fitting theoretical calculations to the measured response of the pile. Although the testing data is poor due to the gage malfunction and the unreasonableness of placing the BD cell, the back-calculation based on *UniPile* software could provide an entire load-displacement curve until the failure. Therefore, the reliability of the design solution could be quantitatively measured. The load-displacement behavior of the testing pile is strain hardening (see Figure 8). It should be noted that the critical value of the pile head's displacement (S_c) stipulated by Vietnam standard 10304-2014 is defined as S_c=0.2S_{gh}+S_e; the value of S_c does not exceed the threshold of 40mm. In this static pile load testing, the value of S_c is 40mm, wherein the recorded value of the pile's shortening (S_e) is approximately 20mm, while the value of S_{gh} is 100mm. Complying with the Vietnam standard, therefore, the ultimate axial load bearing capacity taking at the pile head displacement of 40mm is approximately 45MN.

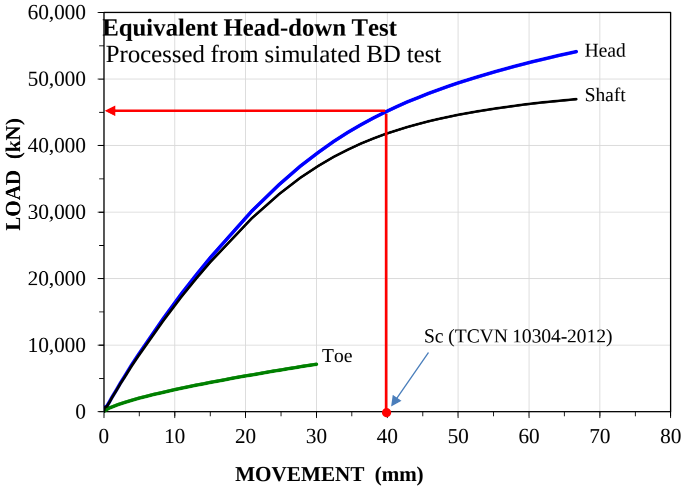

Figure 8. Equivalent head-down static load test.

4. Conclusions

This study provided a case history of a bidirectional static load test on a large cross-sectional bored pile 1.8m in diameter. Based on the analysis, some lessons learned could be enumerated:

The faulty strain reading needs to be determined and excluded from the analysis.

The loading and unloading undermined the usefulness of testing data. It is suggested that the test schedule should be loaded directly from zero to the pre-determined load, e.g., 200% of the sustained load.

The design of the pile foundation needs to be conducted in an effective stress-dependence procedure. Effective stress analysis is not only useful for analyzing the testing data but could take into account some special scenarios such as ground excavation for basement construction, regional settlement, etc., in terms of long-term analysis.

The bidirectional static load test has not been conducted successfully; however, the advanced analysis could remediate the disadvantage of the data shortage and achieve the testing objectives. The load-displacement behavior of the bored pile with strain hardening has been established to validate the design.

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