

BI-DIRECTIONAL STATIC LOAD PILE TEST – CASE STUDIES

Justin St George, Strainstall Singapore Pte Ltd., 1 Bukit Batok Crescent, 04-33 WCEGA Plaza, 658064, Singapore, +65-6561-4628, justin@strainstall.com.sg

Ravi Sundaram, Cengrs Geotechnica Pvt. Ltd., A-100 Sector 63, Noida, Uttar Pradesh, India 9810538095 ravi@cengrs.com

Sorabh Gupta, Cengrs Geotechnica Pvt. Ltd., A-100 Sector 63, Noida, Uttar Pradesh, India 9910861118 sorabh@cengrs.com

ABSTRACT

Bi-Directional Static Load Pile Tests (BDSLT) was performed on a barrette pile of dimensions 1.2 m x 2.8 m extending to 21.278 m below the cut-off level. The test load applied was 10,800 tonnes which can usually not be applied by a traditional static load test. The test results indicated that the pile mobilized an ultimate unit skin friction value of 188.4 T/m² and an end bearing result of 734.5 T/m². Equivalent load-settlement curve indicates settlement of 4.6 mm at 100% the proposed working load, and 7.8 mm for 150% of the working load.

Keywords: Ultimate Load Test, Working Load Test, Bi-Directional Static Load Test, Skin Friction, End Bearing, Kentledge Test

INTRODUCTION

Bi-Directional Static Load Pile Tests (BDSLT) as per ASTM Standard D8169/D8169M-18, 2018 are becoming an increasing trend within the civil construction industry since its inception in 1989 (Leung et al, 2003) due to pile designs becoming larger in both diameter and length to withstand larger test load capacities. This paper presents a case study where the BDSLT method was used to conduct an ultimate load test. It includes the test results obtained and highlight lessons learned.

BI-DIRECTIONAL STATIC LOAD TEST METHODOLOGY

A Bi-Directional Static Load Test (BDSLT) differs from its conventional counterpart (Kentledge Static Load Test) predominantly from the application method of the applied test load (Schmertmann et al, 1998). Instead of the test load being applied from above the test pile by means of a hydraulic jack and counter weight, a BDSLT pile is broken into segments with hydraulic jacks cast within the concrete and uses the geotechnical soil resistance of the test pile as the test load reaction; namely the unit skin friction and unit end bearing.

The BDSLT method results in the applied load profile along the pile length differing from that of a conventional test; as shown in the two plots in Figure 1. A conventional test pile applies the load to the pile head, resulting in the applied load being transferred from the pile head to the pile toe. A BDSLT applies the load from within the test pile; typically positioned around approximately two thirds of the pile length from the pile cut-off level (dependent on actual soil conditions), transferring the applied load equally in the upward and downward directions from the hydraulic jack level. This enables the load to be applied directly to the layers of interest within the test pile, offering a solution for mobilizing stiffer layers within test piles, i.e. test pile socketed into rock, where a de-bonded casing would be required for the equivalent conventional test.

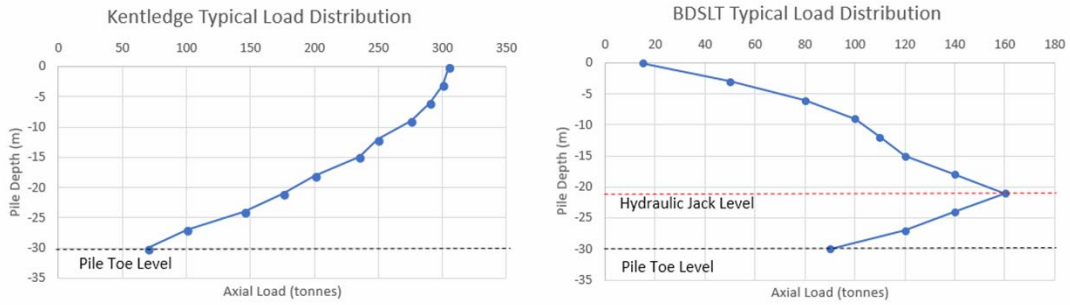


Figure 1: Load Distribution comparison between a conventional kentledge test and a BDSLT

A combination of sacrificial hydraulic jacks are individually calibrated and positioned within the test pile to apply an equal and opposite combined load in both the upward and downward directions, using the skin friction of the segment above the hydraulic jacks as the reaction for the bottom segment, and the combined skin friction and end bearing of the segment below the hydraulic jacks as the reaction for the upper segment. A schematic of a typical BDSLT can be seen in Figure 2.

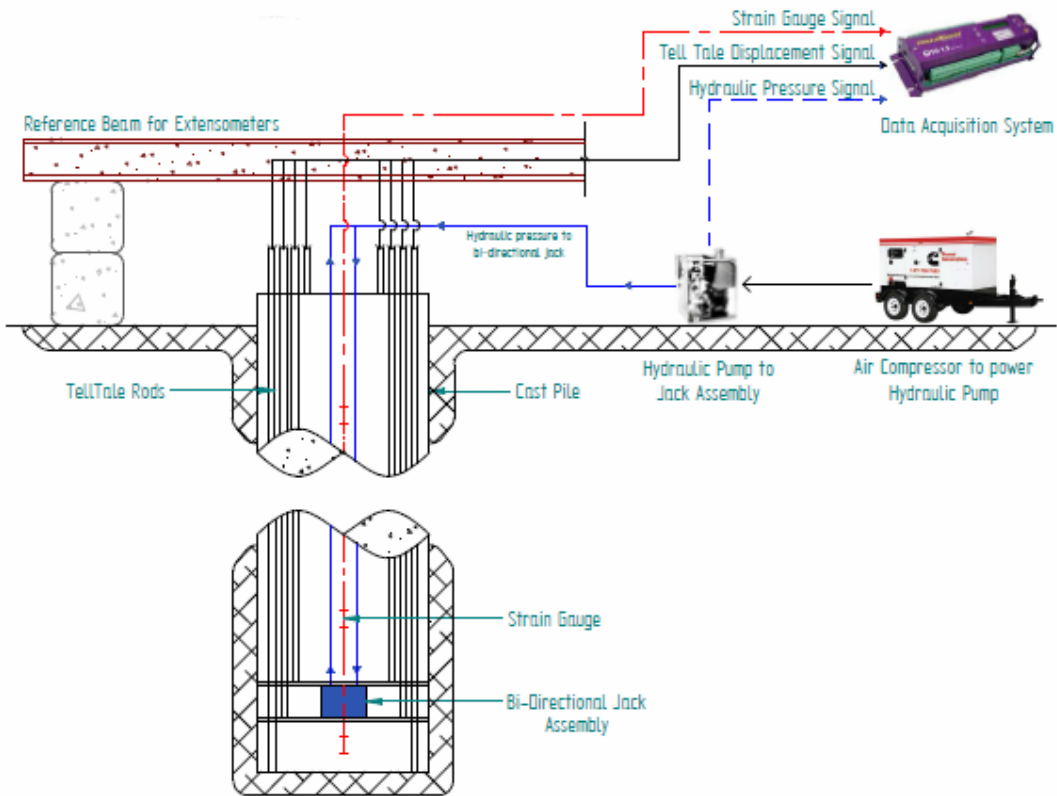


Figure 2: Side View Schematic of a BDSLT (Straininstall scheme)

PROJECT DETAILS

Great World Station was proposed to be developed in Singapore, consisting of the main train station, with attached shopping mall, plus all the connecting tunnels for the underground train lines. The development required excavation to a depth of 31.5m below ground level, resulting in the top 31.5m meters of soil not being of interest to the consultants.

The project consultant was particularly interested in determining the ultimate capacity of the G(III) rock layer; found at 49 m below ground level, based on the nearest borehole which is presented pictorially in Appendix B for reference. The test pile was a barrette pile, with dimension of 1.2m x 2.8m, designed with a length of 21.278 m from cut-off level to pile toe and required an applied test load of 10,800 tonnes. A schematic of the test pile has been included in [Appendix A](#).

Due to the large test load and requirement to fully mobilize the stiffer G(III) layer to determine ultimate geotechnical capacity, a conventional test posed many risks and was deemed unsafe. The BDSLT method was therefore proposed to safely test the pile to required test loads in a safe and controlled manner.

A combination of six no. 900 tonne jacks were positioned at 2.60m above the pile toe, providing a test load of 5,400 tonnes in both the upward and downward direction, resulting in a combined test load of 10,800 tonnes. The test pile was loaded from 0 tonnes to 10,800 tonnes in 5% increments; following the ASTM-D1143 loading schedule, to obtain test results in a higher resolution.

Thirteen levels of concrete embedded strain gauges were installed to the reinforcement bar cage along the pile length prior to casting. Strain gauge results were used to determine the load transfer between each level of strain gauges, which could then be used to determine the ultimate soil/rock resistance to a **known** applied load.

TEST RESULTS

Obtained results achieved an ultimate mobilized unit skin friction value of 188.4 T/m² for the G(III) rock layer, with an end bearing result of 734.5 T/m². An Equivalent top load-pile head settlement curve was constructed to include additional elastic compression of concrete, which provided values of 4.6mm equivalent pile head settlement at 100% of the proposed working load, and 7.8mm for 150% of the working load. Both settlement values falling below the allowable settlement criteria of 7mm and 14mm for 100% and 150% of the working load respectively.

Table 1 below summarizes the ultimate test results achieved. Fig. 3 and 4 present the load Vs Displacement plots for both loading cycles (Cycle 1 from 0-300% of the working load, and Cycle 2 from 300-390% of the working load). Fig. 5 presents the equivalent top loaded settlement curve, including the additional elastic compression of the concrete, while Fig. 6 presents the calculation table for the equivalent top loaded settlement curve calculation.

Table 1. Maximum Design Parameters Obtained During Testing

Load Transfer Zone	Depth (m below GL)	Soil Type	Average SPT-N	Mobilized Unit Shaft Friction (tonnes/m ²)		
				%WL	Skin Friction (tonnes/m ²)	Ks Value
LEVEL 1 to 2	-19.222 to -2.222	SILT G(VI)	5 - 6	390	2.6	N/A
LEVEL 2 to 3	-12.222 to -4.222	SILT G(VI)	10 - 39	325	5.5	1.4
LEVEL 3 to 4	-4.222 to 0.678	SILT G(V)	26 - 48	275	6.3	1.3
LEVEL 4 to 5	0.678 to 2.678	SILT G(V)	46 - 100	390	10.1	1.1
LEVEL 5 to 6	2.678 to 5.678	SILT G(V)	100	390	14.9	1.5
LEVEL 6 to 7	5.678 to 8.678	SILT G(V)	100	390	20.6	2.1
LEVEL 7 to 8	8.678 to 11.678	G(V)	100	325	22.9	2.3
LEVEL 8 to 9	11.678 to 13.678	G(IV)	100	390	30.0	3.0

Load Transfer Zone	Depth (m below GL)	Soil Type	Average SPT-N	Mobilized Unit Shaft Friction (tonnes/m ²)		
				%WL	Skin Friction (tonnes/m ²)	Ks Value
LEVEL 9 to 10	13.678 to 15.678	G(IV)	100	390	39.4	3.9
LEVEL 10 to 11	15.678 to 17.678	G(IV)	100	390	61.1	6.1
LEVEL 11 to J1	17.678 to 18.678	G(III)	100	390	74.7	7.4
LEVEL J1 to 13	18.678 to 20.428	G(III)	100	390	188.4	18.9
Mobilised Unit End Bearing (tonnes/m²)				%WL	End Bearing (tonnes/m²)	kPa
TOE				390	734.5	7345

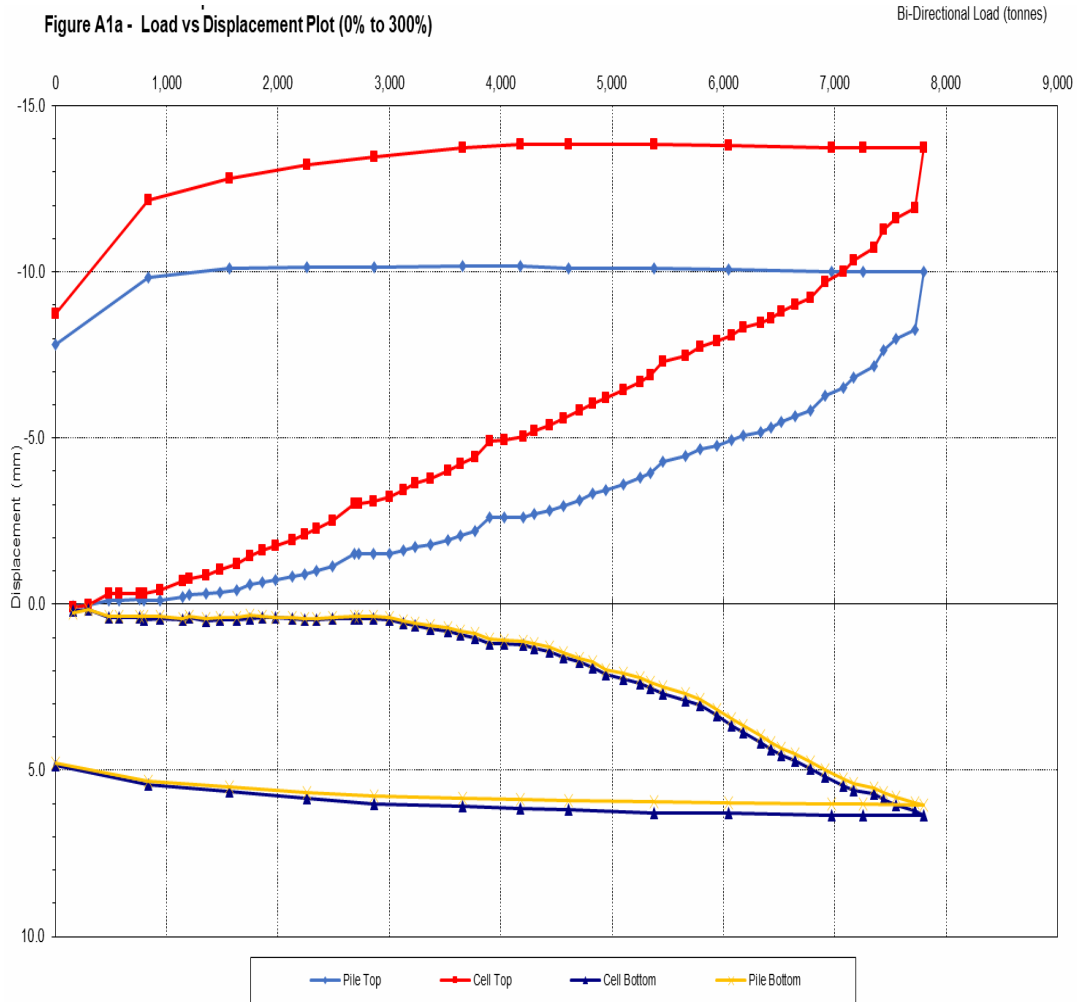


Figure 3. Recorded Settlement of Test Pile Between 0% to 300% of the Test Load.

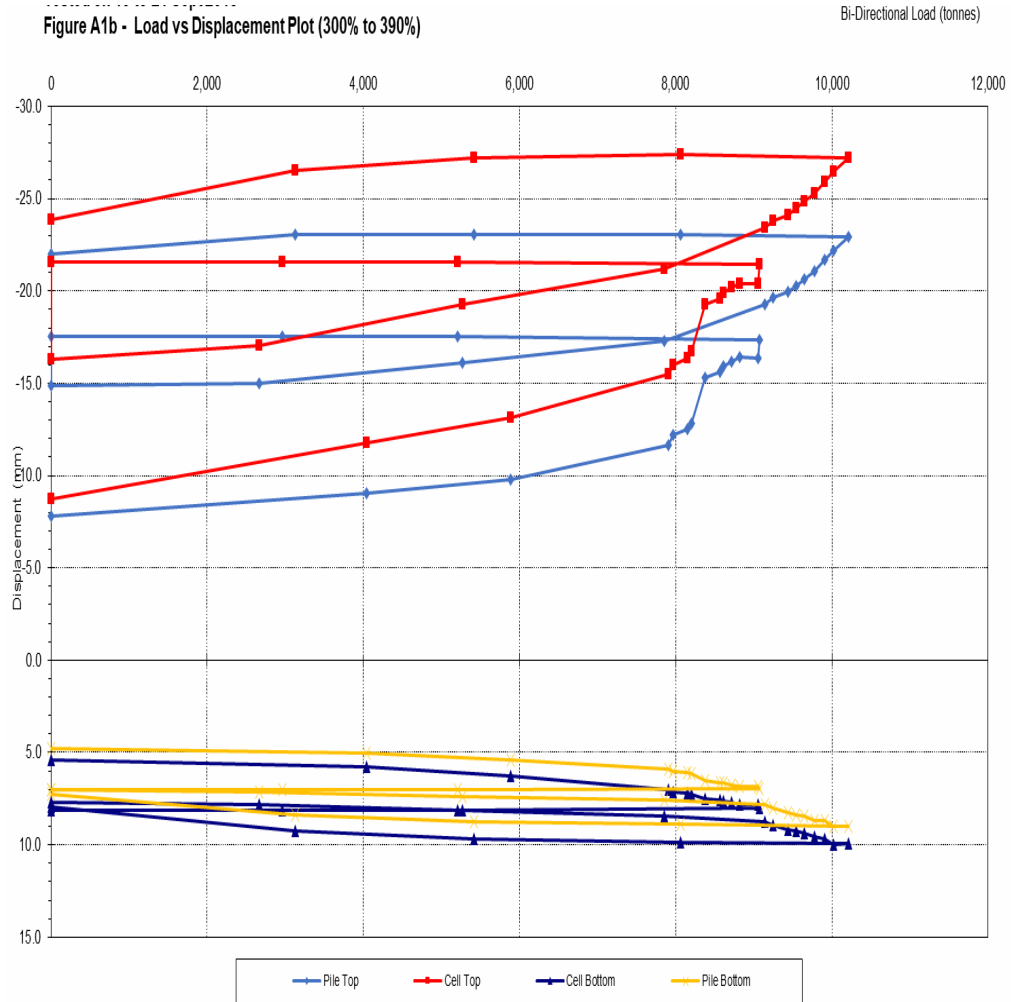


Figure 4. Recorded Settlement of Test Pile between 300% to 390% of the Test Load.

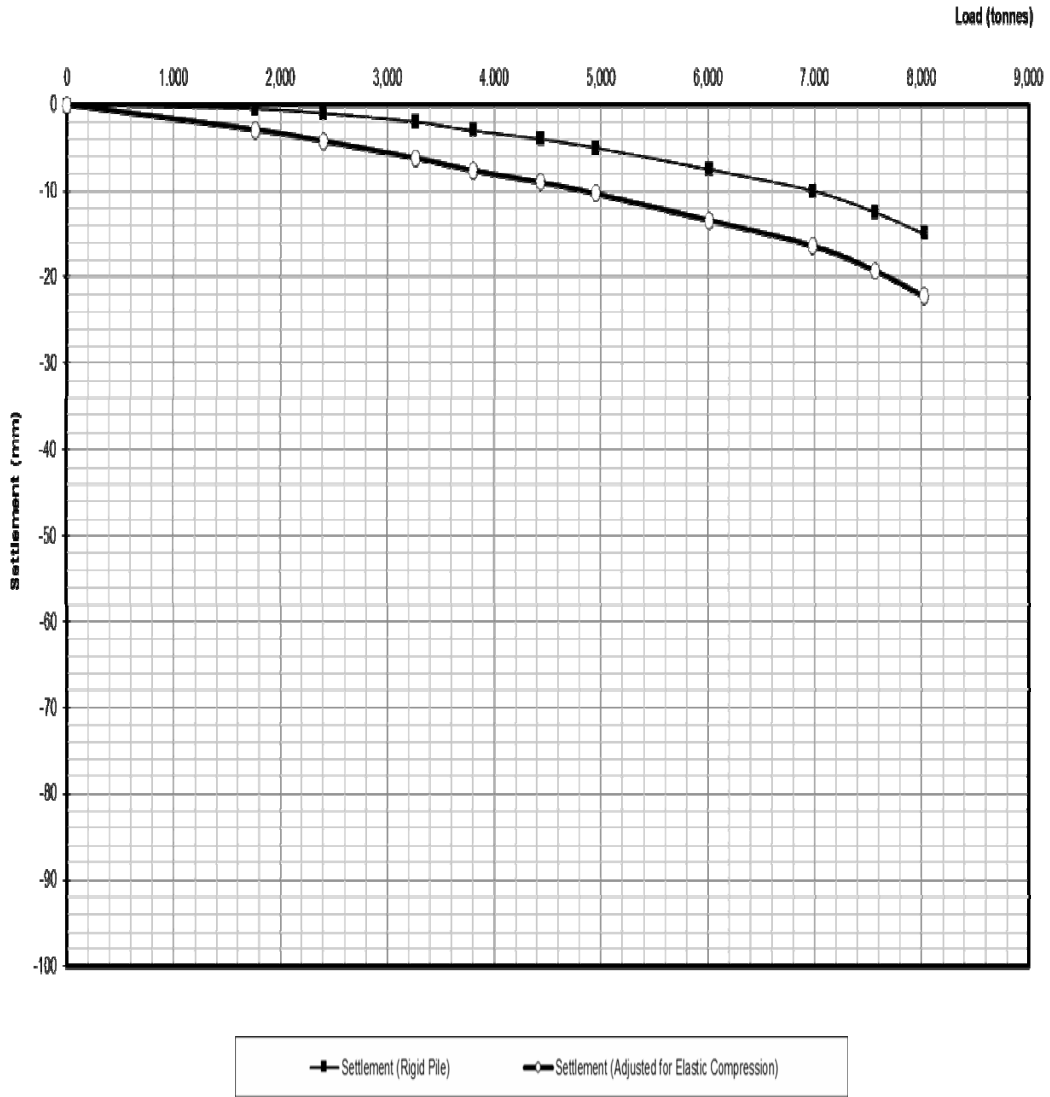


Figure 5. Equivalent Top Loaded Settlement Curve

Pile diameter	2800 x 1200	mm
Friction Centroid Factor (C_f)	0.50	
Length above GL, l_0	0	mm
Length above Jack A below COL, l ($l_1 + l_2$)	18,678	mm
Length above water level	18,678	mm
Height of water level above Jack A	0	mm
Cross Sectional Area of Pile (A)	3.36E+06	mm ²
Elastic Modulus of Concrete (E)	1.72	tonnes/mm ²
Density Concrete (ρ)	2.45	tonnes/m ³
Weight of Concrete above Jack A (W' $l_0 + l$)	154	tonnes
Pile Length Above Jack A ($l_0 + l$)	18,678	mm

Δ BDSLTLT (mm)	$Q_{\downarrow A}$ (tonnes)	$Q_{\downarrow A'}$ (tonnes)	$Q_{\uparrow A}$ (tonnes)	$Q_{\uparrow A'}$ (tonnes)	Equivalent Load (P single) (tonnes)	$\delta_{\downarrow} l_0$ (mm)	$\delta_{\downarrow} l_1 + l_2$ (mm)	δ TLT (mm)	δ BDSLTLT (mm)	$\Delta\delta$ (mm)	Δ BDSLTLT + $\Delta\delta$ (mm)
0.00	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
-0.50	1345	1345	420	420	1765	0.0	2.8	2.8	0.4	2.4	-2.9
-1.00	1820	1820	585	585	2405	0.0	3.7	3.7	0.5	3.2	-4.2
-2.00	2355	2355	910	910	3265	0.0	5.0	5.0	0.8	4.2	-6.2
-3.00	2615	2615	1190	1190	3805	0.0	5.7	5.7	1.1	4.6	-7.6
-4.00	2825	2825	1610	1610	4435	0.0	6.4	6.4	1.4	5.0	-9.0
-5.00	3000	3000	1950	1950	4950	0.0	7.0	7.0	1.7	5.3	-10.3
-7.50	3335	3335	2675	2675	6010	0.0	8.3	8.3	2.4	5.9	-13.4
-10.00	3600	3600	3385	3385	6985	0.0	9.4	9.4	3.0	6.4	-16.4
-12.50	3820	3820	3745	3745	7565	0.0	10.1	10.1	3.3	6.8	-19.3
-15.00	4100	4100	3925	3925	8025	0.0	10.7	10.7	3.5	7.3	-22.3

Figure 6. Equivalent Top Loaded Settlement Curve Calculation

Applying the test load from within the test pile and positioning the hydraulic jacks directly within the G(III) layer allowed successful mobilisation of the lower regions of the test pile. This enabled the test results to confirm the consultants design parameter for the skin friction capacity of the G(III) rock layer; initially proposed at 90 tonnes/m² ultimate capacity. This result provided the consultants with the information required to further optimize the pile design to reduce the pile length for the working test piles.

Bi-Directional Static Load Tests can be beneficial in obtaining test results in difficult soil conditions where large test loads are required. BDSLTLT's can be tailored to obtain the parameters of most interest to the consultants, where the hydraulic jack level can be adjusted to fully mobilize the regions of interest, obtaining ultimate capacities of the soil strata to optimize the pile design.

Careful consideration must be taken when designing the proposed level of the hydraulic jack within the test pile to ensure the upper and lower segment capacities of the test pile are evenly matched approximately 50% each, achieving this is also heavily dependent on the initial geotechnical design parameters provided by the consultants.

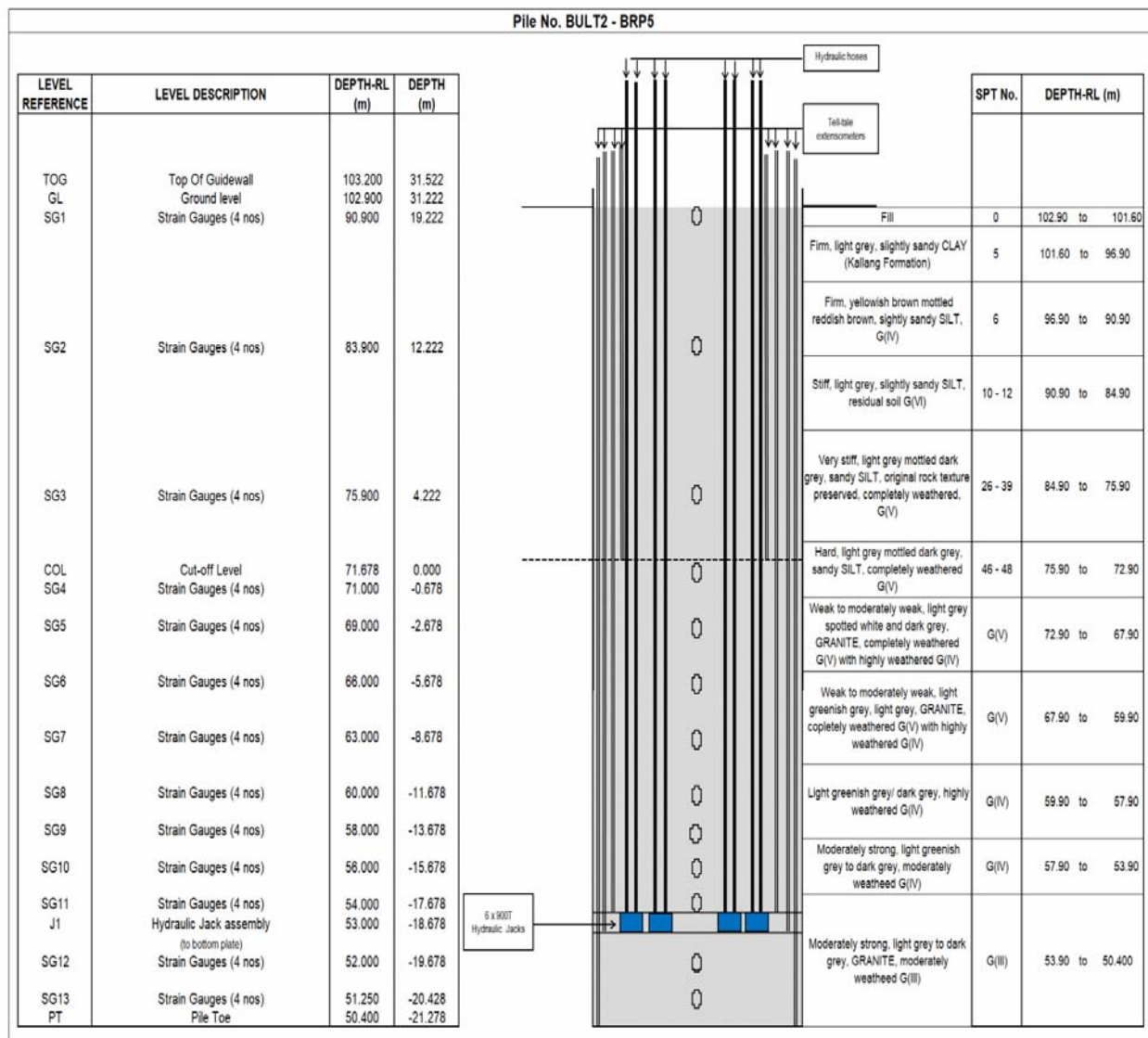
A BDSLTLT test should be precisely planned to ensure that the construction and casting of the test pile is of satisfactory standard to ensure a successful test.

CONCLUDING REMARKS

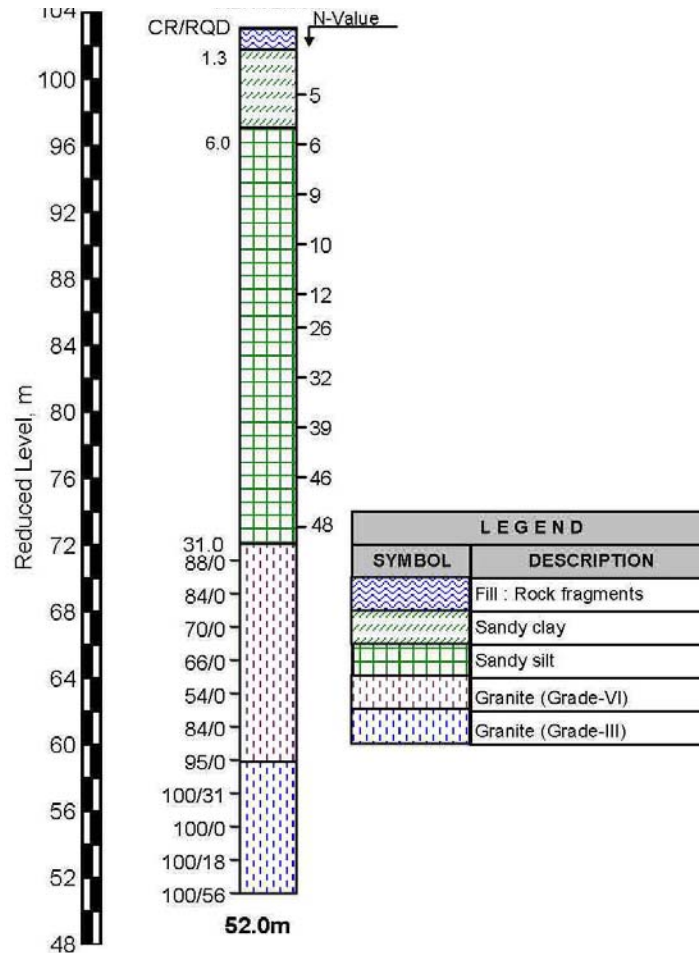
Bi-Directional Static Load Testing (BDSLTL) can be used as an accepted alternative to its conventional counterpart (Kentledge Static Load Test), especially where large test loads are required to mobilize deep foundations. Applying the test load from within the test pile, as well as directly to the stiffer layers found in the lower portion of deep foundations, can result in fully mobilizing the lower layers for the test pile to obtain ultimate soil parameters to verify and optimize the pile design.

The position of the hydraulic jack assembly is crucial in the design of a BDSLTL to ensure the capacity of the upper and lower segments of the test pile are balanced approximately 50/50.

APPENDIX – A: SCHEMATIC OF TEST PILE



APPENDIX – B: BORELOG



REFERENCES

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