Effect of Pile Load Testing Methods – A Case Study in Singapore Old Alluvium Soils

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ABSTRACT: Thomson East Coast Line (TEL) forms part of an extensive underground Mass Rapid Transit (MRT) System catering to Singapore's expanding transportation needs. Eastern section of TEL is 13km long comprises of 10 stations and a mega depot. The mega depot is an integrated structure comprising of 3 rail depots within a single structure. The Stations and the mega depot structure are founded on deep foundation elements comprising of more than 3500 bored piles and barrette piles. All these foundations are located in Old Alluvium (OA) soils, OA in Singapore is a quartenary alluvial deposit consisting of mainly medium to very dense cemented clayey quatzo-feldspathic sands and fine gravels with some coarse gravel and lenses of silt and clay (Pitts, 1984). In this paper, test results of several instrumented pile load tests carried out in these soils are reviewd and various factors that affect the test results are discussed. Behaviour of skin friction resisitance due to different test methods such as Kentledge method of loading and bi-directional load cells are analysed and presented. Base grouting used for enhancing the end bearing resistance of OA strata has an effect on the skin friction resisitance mobilized.

RÉSUMÉ : La ligne de côte est de Thomson (TEL) fait partie d'un système souterrain de Mass Rapid Transit (MRT) souterrain qui répond aux besoins croissants de Singapour en matière de transport. Est section de TEL est de 13 km de long comprend 10 stations et un dépôt méga. Le dépôt est une structure intégrée comprenant 3 dépôts de rails dans une structure unique. Les Stations et la structure mega depot sont fondées sur des éléments de fondation profonde composés de plus de 3000 pieux forés et de pieux barrette. Toutes ces fondations sont situées dans des sols de l'ancien Alluvium (OA), l'OA à Singapour est un dépôt alluvial quaternaire composé principalement de sables quatzo-feldspathiques cimentés de ciments moyens à très denses et de graviers fins avec des graviers grossiers et des lentilles de limon et d'argile (Pitts, 1984). Dans cet article, on examine les résultats d'essais de plusieurs essais de charge de pieux instrumentés effectués dans ces sols et on discute de divers facteurs qui influent sur les résultats du test. Le comportement du frottement cutané dû à différentes méthodes d'essai telles que la méthode de chargement kentledge et les cellules de charge bidirectionnelles sont analysés et présentés. Le piégeage de base utilisé pour améliorer la résistance des couches d'OA à l'extrémité porteuse a un effet sur le frottement de la peau mobilisé..

KEYWORDS: Old Alluvium, Skin friction, End bearing, Kentledge, Bi-directional, Pile load tests

1 INTRODUCTION.

Thomson East Coast Line (TEL) forms part of an extensive underground Mass Rapid Transit (MRT) System catering to Singapore's expanding transportation needs. Eastern section of TEL is 13km long comprises of 10 stations and a mega depot. The mega depot is an integrated structure comprising of 3 rail depots within a single structure. The Stations and the mega depot structure are founded on deep foundation elements comprising of more than 3500 bored piles and barrette piles, bored piles and barrette piles are also used for stations and cut and cover tunnel boxes. All of these deep foundation elements are embedded into Old Alluvium (OA) Soils. The OA is a highly variable material with descriptions ranging from hard clay to gravelly silty sand. There is a strong evidence of over consolidation of OA and Dames and Moore 1983 has reported that the over consolidation ratio is of 4 to 5. Locally, OA soils is classified into 5 sub-units, A (Unweathered) to E (Residual soil) with respect to the extent of weathering conditions. Earlier studies on OA by Orihara and Khoo (1998) indicated that the strength and deformation characteristics of OA vary from location to location. Tan et al (1980) found that the shear strength has no relationship with depth. With such complex behavior of OA, the load transfer behavior of piles in OA need to be well established. Based on several pile load tests carried out in OA soils, Chin et al (1985) found that for piles embedded in OA are mainly friction piles with only 10% of the applied load is carried by end bearing resistance.

In this paper, some of the test results from various ultimate load tests carried out in OA soils along the alignment of TEL have been reviewed and presented, various factors that affect the test results are discussed. The load tests are carried out on instrumented piles by maintained load test method using Kentledge and bi-directional load cells. The entire eastern section of TEL is divided into several civil Contract packages and majority of the piles (2900 numbers) are installed at the mega depot under the contract of T3008. The pile load tests carried out along the eastern section of TEL are identified with their respective contract numbers.

2 PILE LOAD TEST RESULTS

2.1 *Soil profile and Pile load tests*

Figure 1 shows a typical soil profile along the alignment of the eastern section of TEL, the depth of OA strata is found to vary significantly along the alignment. The piles are generally embdedd into the competent stratum of OA(A) which is unweathered or OA(B) which is partially weathered. The pile load tests are essential to achieve an economical pile design, the skin friction and end bearing values should be established from site specific instrumented load tests. The test piles are designed in a way to fully mobilize the skin friction and end bearing resistance in OA strata. Instrumented piles were installed from 16m to more than 64m deep from the ground level in order to determine the skin friction and end bearing resistance in OA strata which is main load bearing strartum.

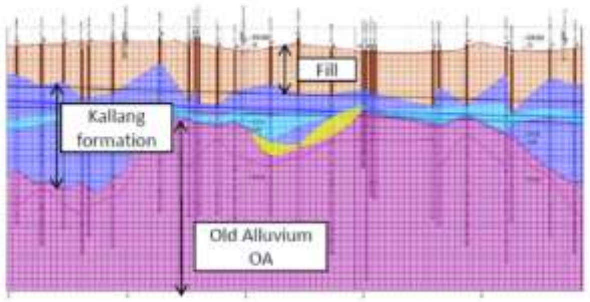

Figure.1 Soil profile along the alignment

Base grouting of piles was proposed to allow the development of end bearing resistance within the displacements of the foundation design of the mega depot, with the excepetion of one test pile, the rest of the test piles at this location are base grouted. Table 1 and Table 2 summarises the various pile load tests carried out using Kentledge and bi-directional load cell method respectively.

Table 1. Summary of pile load tests carried out using Kentledge.

Pile No	Pile dia(m)	Pile length (m)	Working Load (kN)	Test Load (kN)	Remark
T3008-P1	1.0	39.2	7440	23140	BG
T3008-P2	1.0	39.2	6660	22762	BG
T3008-P3	1.2	38.4	9670	29000	BG
T3008-P5	1.0	44.2	5660	17000	NBG
T3008-P6	1.0	34.7	6580	19750	BG
T3008-P9	1.0	38.7	6660	20000	BG
T3008-P10	1.0	37.6	6680	20050	BG
T3008-P11	1.0	44.3	6610	22630	BG
T3008-P12	1.0	41.2	6680	20470	BG
T3008-P13	1.0	31.8	6730	20200	BG
T3008-P14	1.0	39.3	6580	19740	BG
T3008-P15	1.0	39.2	6610	19850	BG
T3008-P16	1.0	35.8	6650	22718	BG
T3008-P17	1.0	45.0	6920	20770	BG
T3008-P19	1.0	47.3	7260	21080	BG
T3008-P21	1.0	42.7	6810	20450	BG
T303-P1	1.2	41.2	11796	23676	NBG
T303-P3	1.2	63.7	9747	29513	NBG
T305-P1	1.5	64.5	18559	33120	NBG
T305-P2	1.5	58.7	18850	36000	NBG
T306-P1	1.2	54.2	10535	26835	NBG
T306-P2	1.2	55.7	12170	24350	NBG
T310-P1	0.8	25.8	3194	9961	NBG
T310-P2	0.5	16.6	1440	3600	NBG

Table 2. Summary of pile load tests carried out using bi-directional load cells

Pile No	Pile size(m)	Pile length (m)	Working Load (kN)	Test Load (kN)	Remark
T3008-P4	1.0	44.0	3650	10950	BG
T3008-P7	1.0	51.1	4100	12300	BG
T3008-P8a	1.0	39.5	6500	19500	BG
T3008-P18	1.2	40.4	9300	27900	BG
T3008-P20	1.2	43.3	9310	27930	BG
T307-P1	1.2	61.4	12570	18860	NBG
T307-P2	1.2	62.3	13820	20730	NBG

BG = base grouting, NBG = no base grouting.

2.2 *Skin Friction and End Bearing resistance of OA*

For all pile load tests, loads are applied at different load cycles up to 3 times of working load or until pile failure. The test results presented and discussed in this paper cover the unweathered OA(A) and partially weathered OA(B) strata. Figure 2 shows the load distribution between skin friction and end bearing resistance at 100% of working load, from this data it is found that more than 90% of the applied load is carried by the skin friction resistance for most of the piles tested. However, as the test load increases, the skin friction contribution reduces to about 60% of the applied load (Figure 3) for some of the piles. It is also found that at the end of the testing, the end bearing resistance for majority of the pile load tests is not fully mobilized.

Figure 4 shows the average mobilized skin friction of piles in OA strata at different applied loads, the minimum value of the mobilized skin friction in OA(A) is 230 kPa and for OA(B) is 180kPa. In local practice, empirical relations are commonly used to relate the skin friction and end bearing resistance in OA with SPT-N values. Earlier published data has shown that the skin friction resistance in OA strata is in the range of 2N – 6N. However, there is not much study done to understand the reasons for such wide variation of skin friction resistance in OA strata. In this paper, an attempt has been made to understand the variation of skin friction resistance in OA strata. Table 3 shows the mobilized skin friction and end bearing resistance of all pile load tests reported in this paper. The mobilized skin friction resistance is found to be from 1.3N to 8.4N. Test T307-P1 has indicated a lowest value of 1.3N as the test was terminated before test completion due to limitation of load cell capacity.

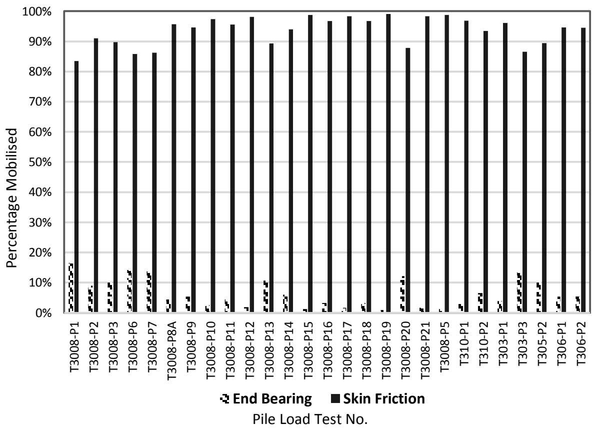

Figure. 2 Distribution of Skin friction and end bearing resistance at Working load

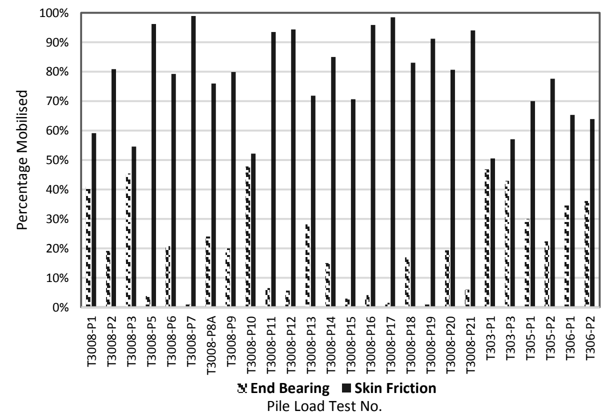

Figure. 3 Distribution of Skin friction and end bearing resistance at end of test load

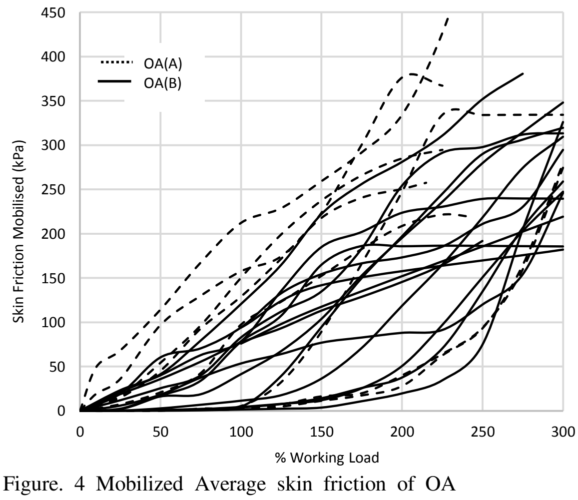

Figure. 4 Mobilized Average skin friction of OA

Table 3. Mobilised skin friction and end bearing resistance

Pile No	Mobilized Skin friction (kPa)		End bearing (kPa)
	OA (B)	OA (A)	
T3008-P1	3.9N	-	12055
T3008-P2	5.3N	-	5554
T3008-P3	4.2N	3.3N	11636
T3008-P4	5.8N	-	4473
T3008-P5	3.4N	2.7N	817
T3008-P6	2.3N	3.2N	5223
T3008-P7	4.4N	-	176
T3008-P8	8.4N	-	5965
T3008-P9	4.8N	-	5110
T3008-P10	3.9N	-	12202
T3008-P11	4.8N	-	1875
T3008-P12	4.7N	-	1467
T3008-P13	2.0N	-	7231
T3008-P14	4.0N	-	3770
T3008-P15	3.5N	-	7416
T3008-P16	5.6N	-	1191
T3008-P17	4.9N	2.8N	402
T3008-P19	4.8N	-	318
T3008-P21	3.0N	-	1559
T303-P1	2.5N	3.0N	10436
T303-P3	2.2N	2.3N	11203
T305-P1	2.6N	2.6N	5626
T305-P2	2.7N	2.9N	4564
T306-P1	2.6N	3.3N	8231
T306-P2	2.7N	2.4N	7763
T310-P1	2.7N	-	5605
T310-P2	3.1N	-	904
T307-P1	1.3N	-	-
T307-P2	2.0N	-	-

With the exception of T3008-P13 and T3008-P6, all the pile load tests carried out at T3008 site show the skin friction resistance in OA(B) fall in the range of 3.0N – 8.4N with an average value of 4.4N. Whereas for the pile load tests at T303 - T306 locations, it shows that the skin friction resistance in OA (B) is in the range of 1.3N to 2.7N with an average value of 2.3N. In general, based on limited data, the average skin friction of OA (A) at T3008 site is 3N and at T303-T307 site locations it is 2.8N.

There are several factors that could affect the skin friction resistance mobilized in OA strata, the most important and significant contributor is the type of soil encountered at the sites. From the review of the grain size distribution for T3008 site data (Figure 5), it shows that the OA strata at this location mainly consist of sandy soils. However, the data of OA strata at T303–T307 sites shows negligible or no sand content, mainly consist of silty clay (Figure 6). The skin friction resistance mobilized appears to be higher in sandy strata of OA as compared to that in silty clay strata of OA.

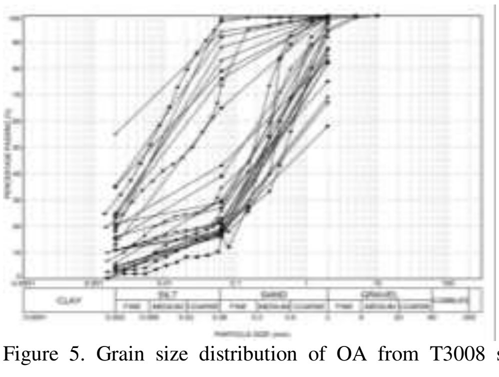

Figure 5. Grain size distribution of OA from T3008 site

The end bearing resistance for most of the pile load tests is not fully mobilized and the mobilized end bearing resistance appears to be within the reasonable range for OA strata. For base grouted test piles, the end bearing resistance is found to be in the range of 176kPa to 12200 kPa and for non-base grouted piles end bearing is found to be in the range of 817 kPa to 11200kPa.

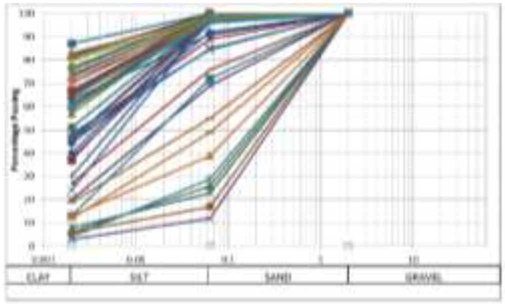

Figure 6. Grain size distribution of OA from T303-T307 site

2.3 *Effect of base grouting*

The mega depot requires a large number of piles (2900 piles) and in order to optimise the pile penetration length, base grouting of piles was proposed to allow for the development of end bearing resistance to enhance the capacity of piles. The base grouting has been carried out through pre-installed grout tubes to the pile base, after 14 days of pile casting, grouting is pumped in with a pressure at about 30 bars. To ensure the effectiveness of base grouting, the pile head is monitored for uplift and is specified not to exceed a movement of 2mm.

Figure 7 shows the mobilized skin friction resistance at different applied loads for piles with and without base grouting. Test results indicated that the base grouting has influenced the skin friction resistance mobilized in OA strata. One of the possible reason could be the process of grouting might have caused the grout to flow to the sides of piles and resulted in an increase in the skin friction resistance. Based on the current test data, it appears that the increase in skin friction resistance is in the region close to the base of the pile. The exact length of pile that has been influenced by grouting could not be ascertained due to insufficient instrumentation at close intervals near the pile toe level. Further detailed study is required to effectively conclude on the extent of this improvement with respect to base grouting.

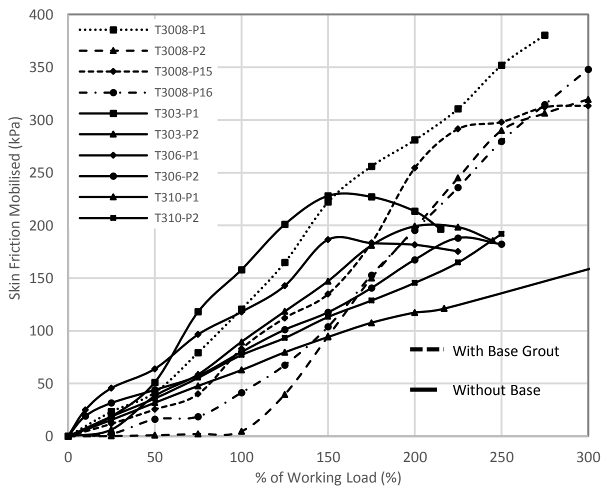

Figure. 7 Mobilized skin friction for piles with and without base grouting.

2.4 *Effect of testing method.*

Majority of pile load tests are carried out using Kentledge loading method and some of the piles are tested using bi-directional load cells due to the requirement of large dead loads and safety concerns. Figure 8 shows the mobilized skin friction in OA strata for different pile load tests with base grouting. The mobilized skin friction resistance for base grouted piles is found to be quite comparable for both the test methods used. When the similar comparisons are made for piles without base grouting (Figure 9), it is found that the mobilized skin friction resistance is smaller for bi-directional load tests than that of Kentledge tests. In bi-directional load tests, careful selection of load cell position is essential to achieve the success of pile testing. For pile T307-P1, the load cell was installed at 5.6m from the pile base and for pile T307-P2 the load cell was installed at 6.8m from pile base. Both the piles could not be tested to the planned test load. For pile T307-P1, the maximum stroke of load cell is reached at 175% of working load as the lower part of pile settled more than 80mm and the test could not be continued. Whereas in the case of test pile T307-P2, the upper part of the pile settled by 80mm and reaching the maximum stroke of load cell resulting the termination of test (150% of working load). For all the other pile load tests (T3008-P4, T3008-P7, T3008-P8a, T3008-P18 and T3008-P20), where load cells were installed at 1.7m to 4.6m from the base of the pile and test has successfully completed with the test loads reaching more than 300% of the working loads. For piles at T3008 tested using bi-directional load cell are base grouted, as a result, the displacements were reduced significantly and the bi-directional load tests were able to complete to the desired test loads.

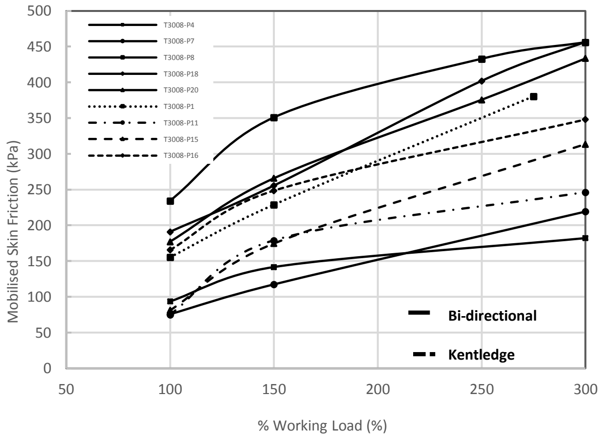

Figure. 8 Mobilized Skin friction of base grouted piles tested usin g Kentledge and Bi-directional load cell

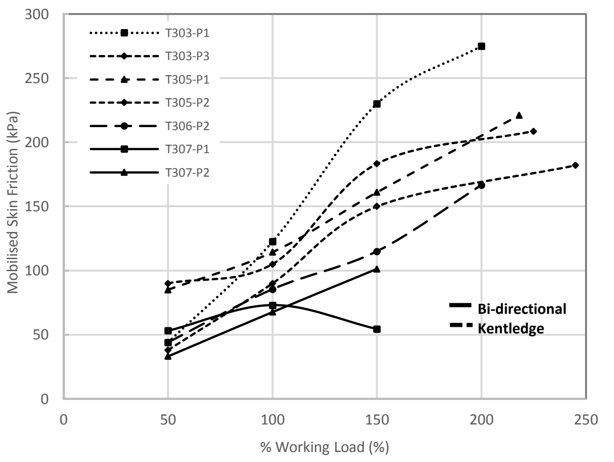

Figure. 9 Mobilized Skin friction of non-base grouted piles tested using Kentledge and Bi-directional load cell

From interpretation of all bi-directional load test results, it can be deduced that this method of testing for frictional piles is very challenging and if the position of load cell is not selected effectively, the chances of premature failure of load test are very high.

3 CONCLUSION

Thomson East Coast Line (TEL) forms part of an extensive underground Mass Rapid Transit (MRT) System catering to Singapore's expanding transportation needs. The eastern section of TEL is 13km long comprises 10 stations and a mega depot. More than 3500 bored piles are required to transfer the structural loads and all these foundation elements are embedded in Old Alluvium (OA) strata. Pile load tests are essential to achieve an economical pile design, skin friction and end bearing values are established from site specific instrumented load tests. From the distribution of skin friction and end bearing resistance, it can be concluded that for the piles installed in OA strata are essentially friction piles with more than 90% contribution of skin friction resistance at working load. The skin friction resistance is found to be affected by the sand content in OA strata, when there is presence of sand content, the average skin friction reisstance in OA(B) is 4.4N, where N is the SPT-N values. For OA(B) with majority of Silty Clay content, the average skin friction resistance is found to be 2.3N. It is also found that base grouting has some influcne on skin friction resistance of piles. One of the possible reason could be the process of grouting might have caused the grout to flow to the sides of piles and resulted in an increase in the skin friction resistance. Further detailed study is required to effectively conclude on the extent of this improvement on skin friction resistance with respect to base grouting. From the studies of load tests using bi-directional load cells and Kentledge methods, it is found that the bi-directional load tests could not be completed for piles without base grouting. From interpretation of all bi-directional load test results, it can be deduced that this method of testing for frictional piles is very challenging, depending on selected load cell position and the chances of premature failure of load test are very high.

4 ACKNOWLEDGEMENTS

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