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PILE CAPACITY REDUCTION OF JACK-IN PILES WITH EMPTY PREBORED HOLE AT META-SEDIMENTARY FORMATION IN PENINSULAR MALAYSIA

LIEW SHAW SHONG
G&P Geotechnics Sdn Bhd, Wisma G&P, 39-5, Jalan Tasik Selatan 3, Bandar Tasik Selatan, Kuala Lumpur 57000, Malaysia

HO SHU FENG
G&P Geotechnics Sdn Bhd, Wisma G&P, 39-5, Jalan Tasik Selatan 3, Bandar Tasik Selatan, Kuala Lumpur, 57000, Malaysia

VOON BOO CHUAN
G&P Geotechnics Sdn Bhd, Wisma G&P, Jalan Tasik Selatan 3, Bandar Tasik Selatan, Kuala Lumpur, 57000, Malaysia

ABSTRACT: Jack-in piling method has gained popularity in deep foundation construction in many city areas of Peninsular Malaysia in recent years due to its advantages of relatively quiet and vibration free pile installation, and more importantly proof loading to all installed piles as well as competitive pricing in pile installation with environmental constraints. However, penetrability of the jack-in pile installation to the required length always become the main concern due to the presence of intermittent hard strata above the designated competent founding hard stratum. As so, jack-in pile with pre-boring technique for achieving minimum pile penetration depth were incorporated to overcome premature pile termination on the intermittent hard strata. This paper presents a case study of investigating a jack-in pile project with empty pre-bored hole in meta-sedimentary formation at central part of Peninsular Malaysia which suffered pile capacity reduction problem with time. It is interesting to note that the inherent softening behavior of the meta-sedimentary formation with localized stress relaxation condition in empty pre-boring hole can significantly reduce soil strength, thus directly affecting the carrying capacity of mostly end bearing jack-in pile. Some lessons learnt from this investigative study are presented for future improvements of jack-in piling, particularly with pre-boring requirement.

INTRODUCTION

Jack-in installation method has gained noticeable popularity lately, particularly for construction in city areas with the obvious advantages that the piles are statically jacked or pressed into the ground without the common environmental impacts in conventional dynamic pile driving method. A common major installation obstruction to jack-in displacement pile is the existence of intermittent hard strata within the subsoil possibly resulted from differential weathering, localized cementation or floating boulders that hinder the jack-in piles from reaching the lower competent founding stratum as designed. In such situation, pre-boring technique is usually adopted to overcome the installation obstruction leading to premature pile termination and to achieve sufficient pile penetration for better pile fixity in resisting lateral loads.

This paper presents lessons learnt from a case investigation consisting of 400mm reinforced concrete (RC) square pile installed in meta-sedimentary formation in Kuala Lumpur with empty pre-bored hole. The installed piles failed to achieve the required pile performance in the maintained load tests. During the investigation, subsurface investigation factual reports, pile foundation design concept, pile construction records, construction method and pile test reports were carefully studied in order to narrow down the probable causes of unfavourable performance of test pile results. Additional maintained load tests were proposed and conducted to verify the probable causes identified in the investigation. Results of both contractually scheduled and investigative maintained load tests are presented and discussed. Some lessons learnt will also be discussed for improvement of the future jack-in pile installation with pre-boring method.

SUBSURFACE CONDITION

Based on geological map, the construction site is underlain by Hawthorndern Formation mainly consisting of metamorphosed sedimentary rocks like phyllite and schist. As observing the rapid rate of disintegration of the exposed weathered bedrock formation and instability of many cut slopes formed in the same formation, it is evidenced that swelling and flaking behaviors of these formations can be prominent when subjecting to stress relaxation. Interpreting from the exploratory boreholes, the overburden weathered materials mostly consist of sandy CLAY and at fairly consistent depth of encountering competent hard stratum (SPT-N ≥50) as shown in Figure 1.

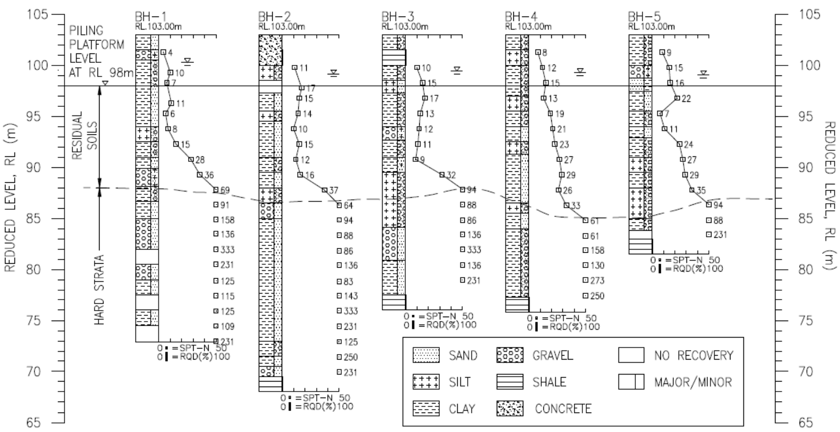


Figure 1. Borehole logs of subsoil profiles

CONSTRUCTION INSTALLATION OF JACK-IN PILES

For this case, jack-in installation method was adopted to install 400mm RC square piles to achieve the specified pile termination criteria (2.2 times of specified pile working load with minimum 30 seconds maintaining period and pile settlement during the maintaining period should not exceed 5mm/cycle for two cycles). The piles were designed to take working load of 1300kN and were statically jacked until 2860kN before termination. All piles were installed in a empty pre-bored hole of 9m below piling platform at RL98m with the aim to facilitate deeper pile penetration. Three (3) different diameters of empty pre-bored hole had been used during the early stage of pile installation. Initially, several piles were installed using 600mm diameter pre-bored hole but it was later changed to 500mm diameter to avoid free standing condition of the pile in the oversized pre-bored hole without adequate lateral support. Finally, majority of the working piles were installed with a compromised 550mm diameter pre-bored hole as 500mm diameter pre-bored hole was found undersized resulting in premature termination for 400mm RC square pile.

Certain piles were terminated either at the base of empty pre-bored hole or with noticeably short penetration below base of the pre-bored hole. These piles were expected to experience capacity reduction resulting from stress relaxation due to overall low confining effective stress near the pile tip as illustrated in Figure 2.

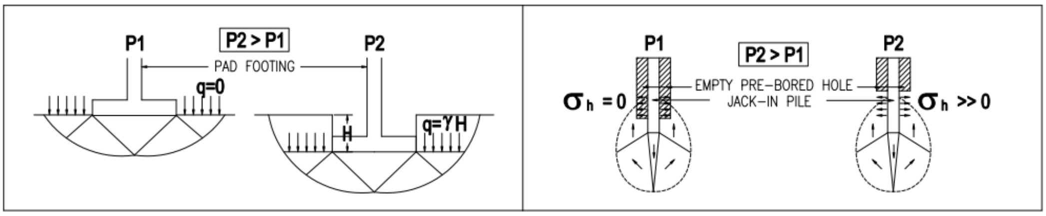


Figure 2. Pressure bulb and plastic zone for shallow foundation and pile foundation

INITIAL MAINTAINED LOAD TESTS

Initial maintained load tests (MLT) were performed on five (5) selected working piles (MLT 1 to MLT 5) to verify the proof load factor, workmanship quality and pile performance.

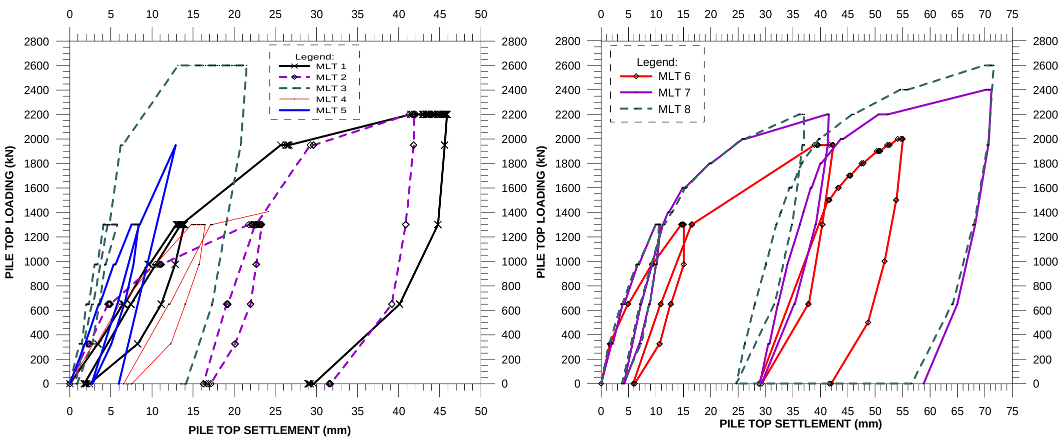
MLT results in Table 1 indicate majority of the initially tested piles settled more than the requirement of 12.5mm at pile working load. MLT 1, 2 and 4 piles with corresponding 0.4m, 0.3m and 0.5m penetration below the base of pre-bored hole had recorded relatively more pile top settlement compared to MLT 3 and 5 piles, which penetrate 3.5m and 4.5m respectively below base of the pre-bored hole. These piles recorded unfavourable performance with excessive pile settlement and were unable to achieve the required maximum test load except for MLT 3. Therefore, it can be reasonably expected that the potential reduction in load carrying capacity of the test pile as indicated in the test results could be strongly related to the pile penetration below the base of empty pre-bored hole. Subsequently, additional MLTs were conducted on specifically selected three (3) working piles with 0.5m, 1.5m and 2.0m penetration below base of 550mm diameter pre-bored hole respectively to verify this suspicion since MLT 1 and 2 were terminated at different maximum jacking forces and pre-bored diameters as explained earlier.

ADDITIONAL MAINTAINED LOAD TESTS

All additional MLT piles (MLT 6 to MLT 8) had been previously installed with termination criterion reaching 2.2 times of working capacity but MLT 6 and 7 piles failed to achieve the required maximum test load, except for MLT 8. This clearly implies the high possibility of pile capacity degradation resulted from stress relaxation. MLT for piles with deeper penetration below the base of pre-bored hole have obviously shown better settlement performance at one (1) time working load in the first cycle. The load-settlement curve of all three test piles in Figure 3(b) has gentler gradient in the first loading cycles whereas the gradient of subsequent reloading cycles becomes steeper. This is the clear evidence of phenomenal soil softening after the termination of jack-in pile. However, further reloading of the pile to higher load in the subsequent load test cycles had allowed the founding soil stratum regaining the soil compactness rendering stiffer pile base response. The test results further enhance the findings of potential stress relaxation at pile tip due to insufficient stress confinement within the effective stress bulb of the end bearing pile tip as a result of insufficient pile penetration below the base of pre-bored hole. The restoration of initial higher pile capacity in second load cycle as a result of further pile penetration into soften subsoil near to the pile tip implies that this is solely a pile settlement problem.

Table 1. Performance summary of the contractually scheduled test piles and additional test piles.

MLT	Pre-bored Diameter (mm)	Pile Penetration below Piling Platform (m)	Max. Jack-in Load at Termination (kN)	Achieved Maximum Test Load (kN)	Pile Top Settlement	
					At Working Load (mm)	At Max. Test Load (mm)
MLT 1	600	9.40	2160	2220 (1.71xWL)	14.0	46.00
MLT 2	500	9.30	2600	2220 (1.71xWL)	23.50	42.00
MLT 3	550	12.50	2860	2600 (2.00xWL)	5.80	21.80
MLT 4	550	9.50	2860	1406 (1.50xWL)	16.50	24.50
MLT 5	550	13.50	2860	1950 (1.50xWL)	8.50	13.00
MLT 6	550	9.50	2860	1950 (1.50xWL)	15.08	42.38
MLT 7	550	10.50	2860	2400 (1.85xWL)	11.29	41.93
MLT 8	550	11.00	2860	2600 (2.00xWL)	10.30	50.35



(a) (b)

Figure 3. Pile top loading (kN) versus pile top settlement for (a) contractually scheduled MLT results and (b) additional MLT results

Note: MLT 1 was terminated at maximum jack-in force lower than other production piles due to the earlier targeted pile working load (WL) is lower (950kN) during 1st pile installation. MLT 2 cannot achieve maximum targeted test load due to insufficient counterweight of the kentledge blocks provided during initial stage of the pile jacking after upgrading the pile working capacity from 950kN to 1300kN.

LESSONS LEARNT AND RECOMMENDATION

Piles installed into pre-bored hole without backfilling the annulus are exposed to the risk of pile tip softening and consequently leads to reduction in pile load carrying capacity and softer response in pile tip stiffness. The base softening effect in the bearing soil stratum affecting the end bearing capacity of the pile can be logically expected when the empty annulus in the pre-bored hole is nearer to the pile base. The empty annulus with virtually zero confining stress provides pre-requisite condition for time dependent stress relaxation of soils to take place especially when the free surface is exposed to water. When the pile has sufficient penetration below the pre-bored base, the stress relaxation effect at the upper most soil (beyond influence zone of the stress relaxation above pile tip) would not affect the effective stress bulb near the pile tip, thus the pile end bearing capacity. Figure 4 shows a schematic diagram of the stress relaxation and the stress bulb of pile tip end bearing.

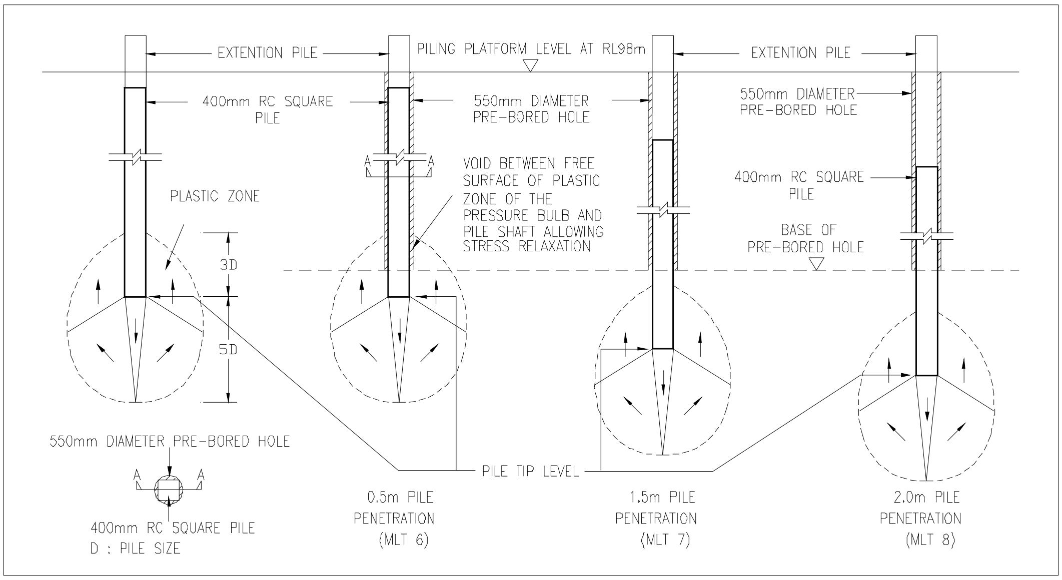


Figure 4. Schematic diagram of stress relaxation and pile stress bulb

The depth of influence zone at pile tip is complicated and influenced by many factors such as angle of shearing resistance of the founding soil at proximity of pile tip, pile diameter, stiffness, in-situ effective stress at pile tip, homogeneity of the soil and etc. For piles in more compressible silty sand with fines content over 15%, the upper plastic zone is between 0.5D and 1.5D and the lower plastic zone ranges from 1.5D to 3D where D is pile size (J. Yang, 2006). Meanwhile, the influence zones for sand with Ø' $=30^0$ are 1D to 3D upwards and 3D to 5D downwards (Hideki Hirayama, 1988). As such, it is worthwhile to seal-off the annulus between oversized pre-bored hole and pile shaft to remove the condition of free surface and to prevent ingression of water potentially leading to softening of pile tip founding materials within the plastic zones of pile tip.

CONCLUSIONS

This paper presents a case investigation of jack-in pile installation method with empty pre-bored hole to achieve deeper pile penetration within the competent meta-sedimentary formation to overcome any premature pile penetration length but unfortunately suffering time dependent pile capacity reduction problem. All the jack-in piles initially achieving the pile termination criteria during installation were primarily due to the high pile capacity developed from temporary high short-terms undrained strength. Subsequently the performance of MLT at selected working piles shows incomparably unfavourable performance with the performance at pile termination. Stress relaxation within the plastic zones of pile tip end bearing due to free annulus surface in empty pre-bored hole and possibly exaggerated with ingress of water at the pile tip softening the founding subsoil are suspected. This localized stress relaxation condition can significantly reduce soil strength, thus directly affecting the carrying capacity and settlement performance of mostly end bearing jack-in pile. The amount of pile capacity reduction is dependent on the subsoil material at pile tip founding level and pile penetration (embedment) below the base of pre-bored hole. However, the consequence of such pile tip softening is in fact a pile settlement problem rather than pile capacity issue. Further pile penetration under sustained imposed pile loading will allow regaining of the pile capacity to balance the pile working load imposed onto the pile.

The performance of three (3) additional MLT on working piles in this investigation provides clear evidence of the varying degree of pile capacity reduction with respect to the corresponding pile penetration below the base of oversized empty pre-bored hole without the annulus backfilled. To overcome the shortcomings, it is worthwhile to consider sealing off the annulus between oversized pre-bored hole and pile shaft to prevent ingression of water and remove the condition of free annulus surface that leads to softening of pile tip material within the plastic zones. This can be easily achieved by placing appropriate amount of cementitious grout into the pre-bored hole before lowering the pile for jacking operation. The depth of cementitious grout sealing shall sufficiently cover the upper plastic zone of the stress bulb after volumetric displacement of grout at pile termination. The recommended minimum grout sealing depth shall be approximately 5 times pile size above the base of pre-bored hole. It is always better to have the grout fully fill up the annulus gap in the empty pre-bored hole to avoid buckling condition of pile if the free standing length in the pre-bored hole is significant.

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