CREATING VALUES THROUGH INNOVATIONS IN JACK-IN PILING SYSTEM – A CASE STUDY IN MALAYSIA

S. S. Liew[a] and J. K. L. Pan[b]

G&P Geotechnics Sdn Bhd, Malaysia. E-mail: [a] ssliew@gnpgroup.com.my, [b] jackpan@gnpgeo.com.my

This paper presents a case study in Malaysia utilizing jack-in piling foundation system for twin residential towers underlain by limestone formation with notorious karstic features. Conventionally, the piles will be jacked to twice its working load with expected high rate of pile damage in limestone areas. Based on site observations and investigation of pile damages during jack-in piling of the test piles, the pile damages were probably related to the highly erratic and karstic features of the limestone bedrock surface, where excessive flexural stress may be generated to the pile body when forcing the pile to penetrate and rest on the erratic limestone surface. A specially devised real time monitoring device was then used to record the pile penetration length and the variation of jack-in reaction load on the piles during pile installation. Instead of wishfully thinking that the pile can be installed to the target jack-in reaction load without pile breakage, it would be more pragmatic to stop the pile jacking immediately at the onset of any distressing signs of pile being observed, likes sudden reduction of jack-in reaction load when approaching the target founding depth. A procedure on pile termination and safe reaction load verification was established to improve the pile survival rate and also to assign appropriate downgraded pile capacity for necessary pile capacity compensation when the target jack-in reaction load cannot be achieved. It is always easier and more economical to deal with an intact pile with downgraded capacity than adding compensation piles to replace the damaged piles with practically no reliable residual carrying capacity.

1. INTRODUCTION

This paper describes the various challenges and innovative solutions adopted in designing the foundation system to create value to the proposed residential condominium project in Ampang, Selangor. It consists of two tower blocks of 18 storeys high for a total 250 units, with levels of podium car park and one level of retail. The site with land size of about 2.5 acres is located within an urban environment and is surrounded by shop lots, high-rise and low-rise residential development see Figure 1.

The authors' company has been engaged by the Design-and-Build contractor to provide an alternative foundation design and also to provide a total engineering solution covering

Advances in Geotechnical Infrastructure
Edited by C. F. Leung, S. H. Goh & R. F. Shen

ISBN: 978-981-07-4948-4 :: doi:10.3850/978-981-07-4948-4_054

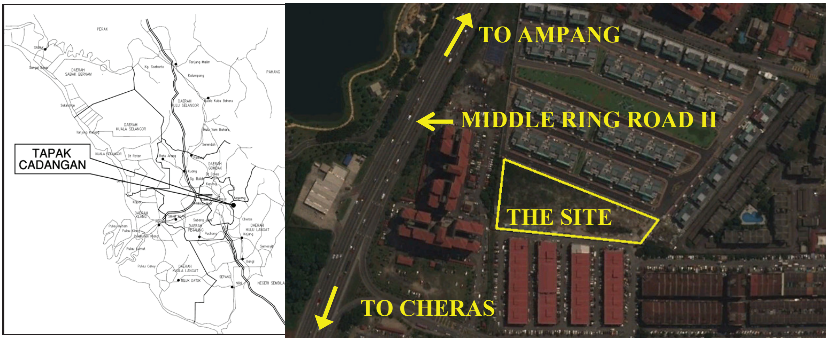

Figure 1. Site location and layout plan.

the Civil and Structural, Geotechnical and Mechanical & Electrical consultancy services for the project.

2. THE SITE

2.1. *Site Geology and Ground Conditions*

According to the geological map of Kuala Lumpur, the site geology consists of Limestone formation. At the time of involvement, there were already 69 boreholes carried out at almost every critical column locations. There are 156 columns in total. The limestone level varies from 16 m to 40 m below ground. The rockhead profile is highly variable with an inclination varying from 30°to more than 50° covering almost half of the site. The overlying overburden soil consists predominantly of clayey SILT and silty SAND with SPT 'N' varying from 5 to 20. At a localized area, silty CLAY with SPT 'N' less than 5 were found at the top 10 m soil layer. In terms of groundwater level, it is relatively high at average level of 3 m below ground.

As part of the verification programme to the provided subsurface information, five additional boreholes were carried out under the full-time supervision from the design office. Two of the boreholes were carried out at the test pile locations while 3 others were carried out to investigate the extent of suspected problematic limestone features.

3. FOUNDATION DESIGN

3.1. *Conforming Design*

The conforming design consists of both bored piles and spun piles. The bored piles were used at locations with large column loads and where cavities were identified from the boreholes, while spun piles were used at other locations. Table 1 summarizes details of the piles used. When the contractor bid for the project, the original tender drawings had a total of 771 nos. of piles. However, during the course of the tender exercise, the tender addendum drawings had been revised to show 830 nos. of piles, which is an increase in total number of piles by about 8%. So it was one of the design objectives to optimize the structural loadings and pile design capacities in order to meet the original tender budget as committed in the fixed price under the Design-and-Build contract.

Table 1. Summary of pile details for conforming design.

	Pile size (mm)	Pile nos. Tender	Pile nos. Tender addendum	Allowable pile capacity (kN)	rock socket length (m)
Bored Pile	900	16	15	4700	2.3
	1050	8	8	6400	2.6
	300	165	156	650	–
	450	37	39	1250	–
Spun Pile	500	545	612	1500	–
	Total	771	830		

3.2. *Alternative Design*

The main objectives of any alternative design are to optimize the conforming design for both cost and time savings. The overall construction period is 30 months with piling works to be completed in 100 calendar days including the pile load tests. In order to achieve the tight programme, it was proposed to do the following:

1. Replace all bored piles with spun piles – this would simplify the construction works, less congestion on site and reduce the mobilization cost. Jack-in piling has advantage of proof loading individually over every installed pile for better performance assurance. The other requirement is to ensure that spun piles can achieve its maximum capacity especially those founded over limestone surface with adverse features such as inclined rockhead and limestone cavities. Cavities were treated with cement-sand grout.
2. Reduce the number of different spun pile sizes of 300, 450 and 500 mm diameter to only 400 mm and 500 mm diameter spun piles as this will streamline the jacking operation with better efficiency and improve site management of pile stockpiles.
3. Upgrade the utilization factor of the spun pile capacity – the conforming design has utilized 75% of the allowable pile structural capacity. This is fairly common practice for spun piles installed in limestone geology with the intention to minimize the possibility of damaged piles when installing the piles on inclined rockhead surface. However such a low blanket utilization factor would result in a higher number of piles. Hence it is proposed that the utilization factor be increased to 85% by careful installation procedures and real-time monitoring for the jacking operation, which will be discussed later. In addition, Class B or C (for starter piles) spun pile with thicker wall are used to minimize risk of pile damage during installation.
4. Remove the pointed pile shoes in the conforming design. It was of the opinion that it would be expensive to design a pointed pile shoe with structural bearing plate welded to a hollow section spun piles taking high jack-in reaction load. One of the benefits with open end pile is that there will be less lateral soil displacement during installation of the piles. In addition, in the event that underpinning is required for piles resting on large cavities, micropiles can be installed through the annulus of the spun piles which would not have been possible had the pile shoes been used.

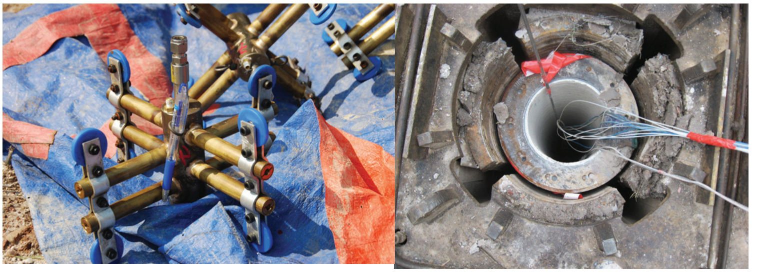

Figure 2. Installation of glostrext instrumentation system for the test pile.

The piles were then redesigned using 400 and 500 mm diameter spun piles, with an 85% utilization factor and to be installed without any pile shoes. The piles were expected to be founded on the limestone rockhead with its capacity mainly derived from the end-bearing. Two 500 mm diameter test piles were specified to verify their design capacities and to explore if the utilization factor can be further optimized. The two test locations were at column M/10 (PLT1) and C/2a (PLT2) where the pile length is about 26 m and 20 m respectively from the jacking platform level (which is about 2 m above the then ground level at site). The two test locations were selected to represent location where the rockhead profile is highly inclined and where the loading is relatively small such that it is easy to install replacement piles if the test piles were damaged during the testing.

The first test pile, PLT1 was carried out without any instrumentation but with the aim of verifying the maximum capacity that the pile can achieve. The jack-in reaction load during installation was recorded manually at this stage as the real-time monitoring device was not ready for the test pile installation. The pile is able to sustain a load of upto 4,600 kN before it failed. The second test pile, PLT2 was carried out with instrumentation using the Global Strain Extensometer (Glostrext) system [Reference 1] to measure the movement of pile segments for global axial strain, load transfer behavior during jacking and also interpreted locked-in/residual stress in the pile after the unloading cycle see Figure 2. PLT 2 failed at a much lower load of 2,200 kN see Figure 3 which is less than twice its working load.

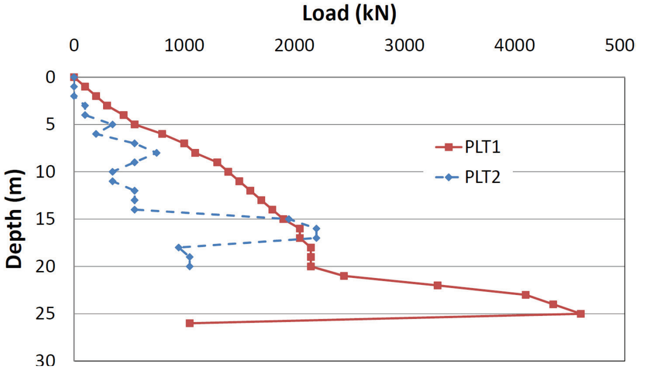

Figure 3. Jacking installation records of test piles PLT1 and PLT2.

Table 2. Summary of pile details for the proposed and final alternative design.

	Pile size (mm)	Before pile load test		Final after pile load test	
		Pile nos.	Proposed pile capacity (kN)	Pile nos.	Proposed revised pile capacity (kN)
Spun Pile	400	43	1100	1148	1200
	500	725	1700	-	-
	Total	768			

Based on the test pile results, it appears that the pile capacity achieved from the 500 mm diameter pile was much less than its structural capacity in PLT2. It was also found that the existing weak ground condition does not permit the jacking rig to take excessive reaction weight for larger jacking reaction. Hence the smaller 400 mm diameter pile size with a lower jack-in reaction load was preferred and the alternative pile design was then revised accordingly. A third test pile, PLT3 (column I/8) was then carried out on a 400 mm diameter spun pile to twice its design load, which was optimized to 1,200 kN. The pile was jacked and terminated at a load of 2,400 kN. The final proposed alternative design is shown in the Table 2.

4. INNOVATIVE CONSTRUCTION APPROACHES

4.1. *Pile Installation Using Real-time Monitoring for Pile Jacking Operation*

One of the main challenges on this project is to optimize the pile capacity utilization factor during pile installation without overstressing or damaging the piles, especially piles which are founded on highly inclined or erratic rockhead. The design team together with the piling contractor and specialist instrumentation contractor came up with an electronic recording system monitoring the pile jack-in reaction load with pile penetration depth while the pile is being installed. To optimize the data storage for useful jacking operational parameter, the data logging system will only record the measurements during the jacking operation and not record when the jacking clamps are released for lifting up to the next jacking operation repeatedly. The main feature of data logger is the visualized user interface and monitoring output that permit efficient judgment to the rig operator during the installation so that timely decisions can be made to control the jacking operation during the course of pile installation see Figure 4.

A comparison between the manual pile installation record and pile installation recording by real time monitoring data logger on the same installed pile is shown in Figure 5. It can be seen that the data logger provides much better reliability and more data points.

A standard pile jacking procedure was formulated to prevent overstressing the pile. The jacking operation will be stopped at 100%, 150% and 200% of the allowable pile capacity for thorough checking of the results. Under normal circumstances, whereby the pile is successfully jacked to twice its allowable capacity, the pile will be terminated by maintaining the jack-in reaction load for at least 20 seconds with an incremental pile head settlement of not exceeding 2 mm. This termination checking is carried out three times to verify the pile performance. During the installation, if there is an observable reduction of pile reaction load increment and/or increasing rate of pile penetration being recorded, the pile jacking

Figure 4. Photo showing wire spring LVDT penetration decoder mounted magnetically onto the jacking frame, pressure transducer to measure jacking pressure and LCD panel placed inside the operator cabin for immediate feedback on monitoring results.

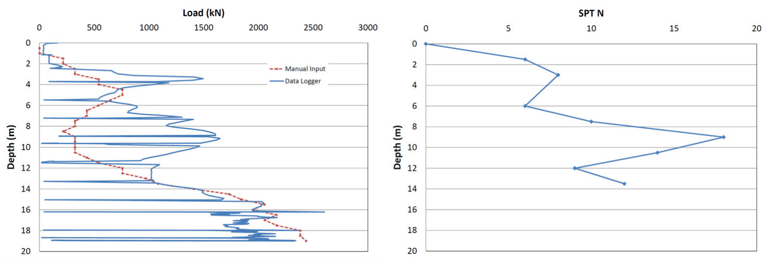

Figure 5. Comparison between jacking pressure recorded manually compared to data logger, which is more consistent with the SPT N values in the nearest borehole.

operation will be ceased and the pile will be re-jacked to 95% of the final jack-in reaction load achieved with the three-time termination criteria achieved. The allowable pile capacity is then downgraded to half of the reduced –in reaction load. This is carried out so that the pile can still take a reduced load instead of total loss in capacity if the piles were structurally damaged due to continued proof loading to twice its design working load. By directly converting the jacking pressure data into graphical format real time, it is much easier and faster for both the operator and Resident Engineer to assess the condition of the piles during the course of jacking operation and make prompt decisions as to whether down-grading will be recommended.

4.2. *Reduction of Cooling Time after Welding of Pile Joints*

The construction programme allowed for the piling works is 100 days or 14 weeks which is considered very tight. In order to meet this deadline, the contractor has mobilized 3 numbers of piling rigs. The average pile points with two welding joints would require an installation time of about two hours. At this rate, one rig can only construct about four pile points per day. For the total 1148 pile points, this will require at least 16 weeks excluding mobilization and pile testing. Hence it is important to review the individual working processes to find ways to expedite the work. One of the most time-consuming activities is the waiting time of at least 30 minutes after joint welding before re-jacking the next pile section. Table 3 summarizes the time required to install a typical pile at this site.

The 30 minutes waiting time criterion originated from previous good practice for structural pile joint welding considering potential tensile stress generated from high impact

Table 3. Average timing for installing a 25 m long pile with 2 welded joints.

Activity	Average time (minutes)	Fraction of time(%)
Handling Starter Pile	6	4.6
Install Starter Pile	8	6.2
Welding 1st Joint	13	10.0
Cooling time	30*	23.1
Install 1st Extension	8	6.2
Welding 2nd Joint	13	10.0
Cooling time	30*	23.1
Install 2nd Extension	13	10.0
Cut Pile	9	6.9
Total	130	100

*Note: Typical waiting time for good practice in pile joint welding

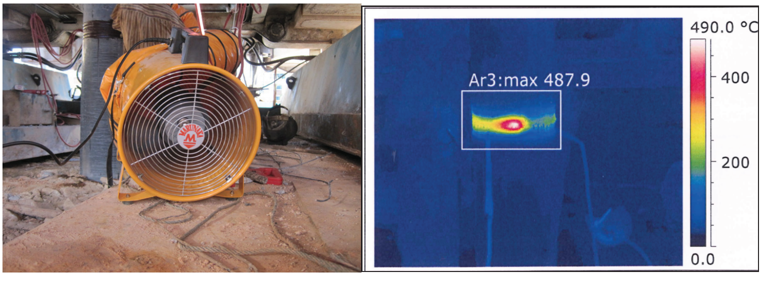

Figure 6. Blower fan used to stimulate forced ventilation condition and a typical thermal imaging results indicating temperature of welded section.

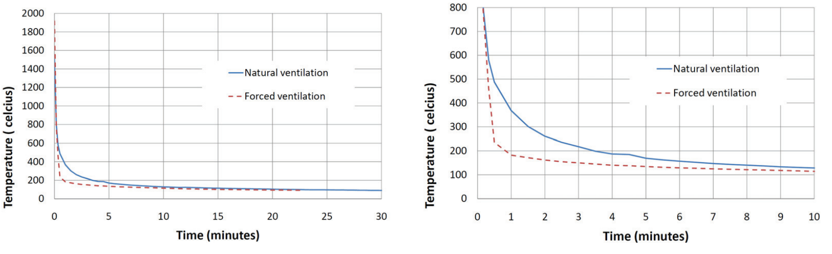

Figure 7. Comparison on drop in temperature under naturally and forced ventilated conditions for 30 minutes (left) and zooming in on first 10 minutes (right).

force during driven pile installation. Hence, the design team explored and carried out a thermal imaging test to compare the rate of reduction in temperature of a naturally ventilated weld compared to another one with forced ventilation using a blower fan see Figure 6.

The results show that similar cooling effect for a forced ventilation weld could be achieved in 5 to 10 minutes compared to a naturally ventilated weld in 30 minutes see Figure 7. It was also observed that the rate of cooling for the critical temperature range of 800 to 500°C, is similar for both the natural and forced ventilation conditions, to prevent

Table 4. Comparison of design and As-built pile quantities.

Description	Design	As-built
Total number of 400 mm diameter spun piles	1148	1244
Average pile length	23.0 m	23.5 m (supply length of 25.8 m)

micro-cracking of the welded joints due to rapid cooling [Reference 2]. And since the jacking operation generally has no serious axial tensile stress compared to the conventional impact driving pile system, the waiting time was revised to 5 minutes thus reducing the installation time of each pile point by $2 \times 25 = 50$ minutes. Instead of installation 4 piles per rig per day, the production rate has increased to 6–7 pile points per rig per day.

5. REVIEW OF AS-BUILT PILE STATISTICS

Table 4 shows the total number of piles constructed on site. There were 96 nos. or 8% of piles added mainly to compensate for the downgraded pile capacities. It could have been much worse had the monitoring system not been used to downgrade and avoid overstressing of piles. There were 336 nos. of downgraded piles downgraded which could have failed totally had they been jacked to twice its working load. This would mean at least 29% (for 1 to 1 replacement) and possibly upto 40% of the piles could need to be added. In fact, more than 90% of the downgraded piles were still able to take more than 2/3 of its original design capacity. Pile wastages due to cutting-off of supply lengths above the then ground level was also controlled to less than 10% by careful monitoring of the jack-in reaction load using the real-time data logger monitoring system.

6. CONCLUSION

This case study demonstrated the values created through innovations and improvements to existing practice of jack-in piling system in limestone geology. The use of real-time monitoring for jacking operation has enabled the pile capacity utilization factor to be maximized and preventing overstressing of the piles. In addition, the reduction of cooling time after welding of pile joints has also shortened the installation time significantly. The proposed piling system is highly recommended to be adopted especially for site with difficult ground conditions.

REFERENCES

1. Wang Huei-Sen, "Effect of Welding Variables on Cooling Rate and Pitting Corrosion Resistance in Super Duplex Stainless Weldments," *Materials Transactions of The Japan Institute of Metals*, Vol. **46**, No. 3 (2005) pp. 593–601.
2. Abdul Aziz Hanifah and Lee Sieng Kai, "Application of Global Strain Extensometer (Glostrext) method for instrumented bored piles in malaysia," 10th *International Conference on Piling and Deep Foundation*, Amsterdam (2006).