# PERFORMANCE OF JACK-IN PILE FOUNDATION IN WEATHERED GRANITE

Chee-Meng CHOW[1] and Yean-Chin TAN[2]
[1]*Asscoiate Director, G&P Geotechnics Sdn Bhd, Kuala Lumpur, Malaysia*
[2]*Director, G&P Geotechnics Sdn Bhd, Kuala Lumpur, Malaysia*
*E-mail*: gnp-geo@gnpgroup.com.my

**ABSTRACT:** Jack-in pile foundation has been successfully adopted in Malaysia since the 1990s and currently, large diameter spun piles up to 600mm in diameter with working load up to 3000kN have been successfully adopted for high-rise buildings of up to 45-storeys. The use of jack-in piles offer advantages in terms of low noise and vibration during pile installation which is important for construction works in developed urban areas. As jack-in pile system is relatively new compared to existing system such as driven or bored piles, uncertainties related to assessment of geotechnical capacity, i.e. shaft and base resistance, load-settlement characteristics (stiffness) and determination of appropriate pile installation criteria still needs to be addressed. In this paper, results of static load tests from four sites in weathered granite is presented to discuss the performance of the jack-in pile foundation system. Instrumented pile load tests were also carried out to determine the load transfer characteristics of the piles. Based on the load test results, preliminary correlations for shaft friction with SPT-N for jack-in pile and suitable termination criteria for jack-in pile installation in weathered granite are presented.

## 1. INTRODUCTION

Jack-in pile foundation has been successfully adopted in Malaysia since the 1990s and currently, large diameter spun piles of up to 600mm diameter with working loads of up to 3000kN have been successfully adopted for high-rise buildings of up to 45-storeys. The popularity of jack-in pile foundation systems especially for construction works in urban areas is due to their relatively lower noise and lower vibration compared to conventional piling systems such as driven piles. Jack-in pile foundation also offers advantages in terms of faster construction rates, better quality control, less pile damage and cleaner site conditions as it does not require the use of stabilizing liquid/drilling fluid typically associated with bored piles and micropiles. In practice, piles installed using the jack-in method are expected to be shorter than driven piles. This is because driven piles are often driven to greater length than is truly necessary due to the uncertainties associated with their geotechnical capacity during driving. However, jack-in piles are jacked to the specified capacity and therefore, result in savings without compromising the safety, serviceability requirements and integrity of the pile foundation. However, like all available systems, jack-in piles also have their drawbacks, such as the need for a relatively stronger platform to support large and heavy machinery and a generally larger working area to install the piles. However, the drawbacks can be managed if the designer is aware of these limitations and jack-in pile foundation systems have been successfully adopted in congested high-rise developments, piling works at different platform levels with limited working space and works carried out at lower ground level associated with basement construction.

Table 1 summarises some key technical data of high capacity jack-in pile machine commonly used in Malaysia while Figure 1 shows typical high capacity jack-in pile machines in Malaysia with maximum jacking force up to 7000kN.

Table 1 Key technical data of some high capacity jack-in pile machines commonly used in Malaysia

| ITEM | TECHNICAL DATA |
|---|---|
| Maximum Jacking Force | 6000-7000kN |
| Applicable Spun Pile Diameter | 250mm to 600mm |
| Applicable RC Square Pile Size | 250mm to 400mm |
| Self Weight (Excluding counterweight) | 178t to 200t |
| Overall dimension (Length x Width x Height) | 11.1 x 10.0 x 9.1<br>13.55 x 12.0 x 7.44 |
| Minimum clearance required for piling works (Centre jacking) | 5.5m to 6.9m |
| Bearing pressure on sleeper | Up to 175kN/m$^2$ |

Figure 1 Typical high capacity jack-in pile machine in Malaysia.

In this paper, discussion on some observed jack-in pile performance in weathered granite formation is presented based on results of static load tests. Preliminary correlations for shaft resistance with SPT-N for jack-in pile and suitable termination criteria for jack-in pile installation in weathered granite are also presented.

## 2. PERFORMANCE OF JACK-IN PILE IN WEATHERED GRANITE

### 2.1 Case Histories

In this paper, case histories from four (4) sites in the city of Kuala Lumpur and state of Selangor, Malaysia are presented. All four case histories adopted jack-in pile foundations to support the high-rise structures with the following details:

a) Site A – 31-storey condominium/apartment
b) Site B – 45-storey condominium/apartment
c) Site C – 40 to 43-storey condominium/apartment
d) Site D – 15-storey condominium/apartment

Details of the jack-in pile adopted and tested in the above four sites are summarised in Tables 2, 3, 4 and 5.

Table 2 Jack-in pile details for Site A.

| PILE TYPE | WORKING LOAD | TERMINATION CRITERIA* |
|---|---|---|
| ϕ450mm spun pile (thickness: 100mm) | 1520kN | Jacked to 2.5 times working load with holding time of 30 seconds |
| ϕ500mm spun pile (thickness: 110mm) | 2300kN | Jacked to 2.0 times working load with holding time of 30 seconds |

Table 3 Jack-in pile details for Site B.

| PILE TYPE | WORKING LOAD | TERMINATION CRITERIA* |
|---|---|---|
| ϕ450mm spun pile (thickness : 80mm) | 1600kN | Jacked to 2.1 times working load with holding time of 60 seconds |
| ϕ500mm spun pile (thickness: 90mm) | 2100kN | |
| ϕ600mm spun pile (thickness: 100mm) | 2800kN | |

Table 4 Jack-in pile details for Site C.

| PILE TYPE | WORKING LOAD | TERMINATION CRITERIA* |
|---|---|---|
| ϕ450mm spun pile (thickness: 100mm) | 1900kN | Jacked to 2.0 times working load with holding time of 30 seconds |
| ϕ500mm spun pile (thickness: 110mm) | 2300kN | |
| ϕ600mm spun pile (thickness: 110mm) | 3000kN | |

Table 5 Jack-in pile details for Site D.

| PILE TYPE | WORKING LOAD | TERMINATION CRITERIA* |
|---|---|---|
| ϕ400mm spun pile (thickness: 100mm) | 1700kN | Jacked to 2.0 times working load with holding time of 30 seconds |
| ϕ500mm spun pile (thickness: 110mm) | 2300kN | |
| ϕ600mm spun pile (thickness: 110mm) | 3000kN | |

*Maximum jack-in force with holding time of 30-seconds is carried out for a minimum of two (2) cycles.

*Note: It can be observed that different termination criteria were adopted for the four different sites with maximum jack-in force ranging from 2.0 to 2.5 times the pile working load and holding time varying from 30-seconds to 60-seconds. The reasons behind this is due to technical research carried out by the Authors to find the most optimum maximum jack-in force and to satisfy other parties (e.g. Clients, Structural Engineers, etc.) who are not familiar with the relatively new jack-in foundation system. As such, sometimes more conservative maximum jack-in force and holding time is adopted for certain projects. Generally, maximum jack-in force of 2.0 times the pile working working load with holding time of 30-seconds is sufficient (2 cycles). The implication of the difference in maximum jack-in pressure and holding time is not expected to affect the findings in this paper.*

### 2.2 Subsurface Information

All four case histories presented in this paper are underlain by Granite Formation with overburden materials mainly consisting of silty SAND/sandy SILT with variable thicknesses. Typical borehole profiles for one of the site (Site B) are shown in Figure 2.

Subsoil conditions of all the four sites typically consist of weathered granite formation with increasing SPT-N with depth. Boulders were also encountered during subsurface investigation and actual piling works. The presence of the boulders is expected in such weathered granite formation. Due to the presence of boulders and intermediate hard layers, some preboring was also carried out to facilitate pile installation works.

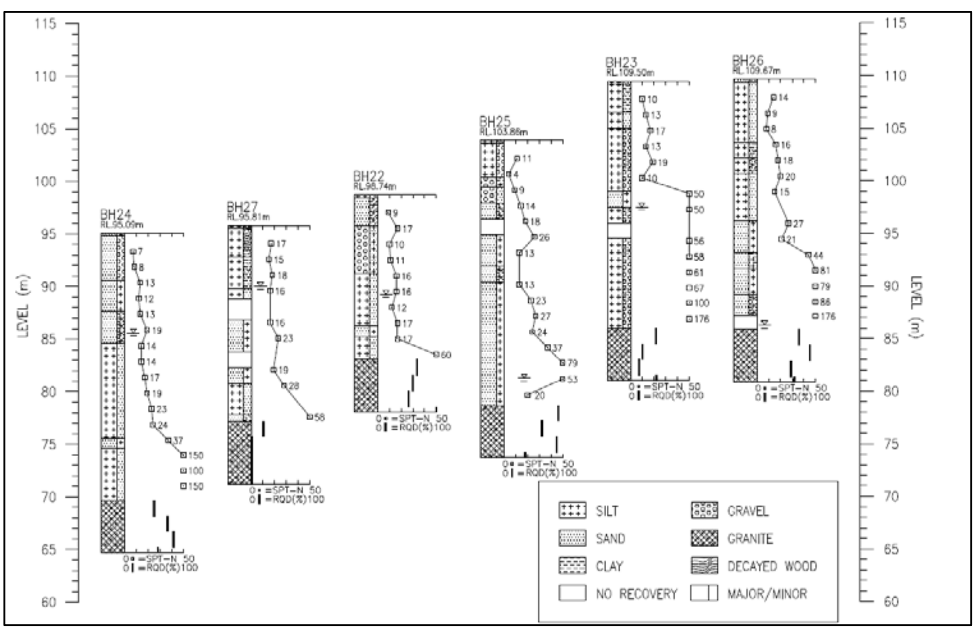


Figure 2 Borehole profiles at Site B.

### 2.2 Static Load Tests

A total of twenty-two (22) numbers of static load tests were carried out for the above four sites and the results are summarised in Table 6. All the piles selected for testing at the above four sites passed with settlement within allowable limits.

Table 6 Summary of pile static load tests.

| Pile Diameter (mm) | Pile Length (m) | Settlement (mm) | | Remarks |
|---|---|---|---|---|
| | | WL | 2*WL | |
| **Site A** | | | | |
| 450 | 10.5 | 6.36 | 12.89 | - |
| 500 | 37.0 | 4.53 | 11.89 | - |
| 500 | 20.6 | 9.23 | 20.46 | 20m preboring |
| **Site B** | | | | |
| 450 | 12.0 | 3.04 | 6.96 | - |
| 500 | 17.7 | 7.82 | 17.81 | - |
| 500 | 22.6 | 5.39 | 12.77 | - |
| 500 | 9.5 | 5.41 | 15.03 | - |
| 500* | 6.5 | 8.32 | 19.73 | - |
| 600 | 17.7 | 4.82 | 12.16 | - |
| 600* | 20.7 | 5.57 | 13.05 | - |
| 600 | 14.5 | 9.88 | 21.28 | - |
| **Site C** | | | | |
| 450 | 27.6 | 8.88 | 18.21 | - |
| 450 | 32.5 | 6.72 | 15.93 | - |
| 500 | 24.7 | 8.85 | 22.22 | Instrumented (PTP-1) |
| 600 | 27.0 | 8.62 | 17.67 | - |
| 600 | 17.5 | 7.35 | 16.37 | - |
| 600 | 23.0 | 7.99 | 20.75 | Instrumented (PTP-2) |
| 600 | 21.4 | 7.37 | 17.30 | Instrumented (PTP-3) |
| **Site D** | | | | |
| 400 | 7.5 | 9.23 | 19.99 | - |
| 500 | 16.5 | 6.41 | 21.83 | - |
| 600 | 34.8 | 8.48 | 16.76 | Instrumented (PTP-1)<br><br>Pile tested up till 2.5*WL.<br>Settlement at 2.5*WL: 23.84mm.<br>Residual settlement after unloading from 2.5*WL: 5.48mm. |
| 600 | 25.5 | 7.46 | 15.38 | Instrumented (PTP-2)<br><br>Pile tested up till 2.5*WL.<br>Settlement at 2.5*WL: 21.90mm.<br>Residual settlement after unloading from 2.5*WL: 6.33mm. |

*Note: WL denotes pile working load.*

*Plots of load-settlement for pile tested in Site B are shown in Figure 3.

From the pile static load test results, the followings are observed:

a) Pile performance is satisfactory for pile lengths as short as 6.5m (Site B) with settlement at working load and two times working load of 8.32mm and 19.73mm respectively.

b) Pile performance is satisfactory for piles where preboring has been carried out. This demonstrates the validity of the assumption that the geotechnical capacity of the pile is a function of the jack-in force during pile installation.

c) The termination criterion adopted of jacking to two times of working load with holding time of 30-seconds is adequate. In fact, from the load test results (Table 6 and Figure 3), there is room for possible optimisation as the piles can support up to two times working load without showing signs of plunging failure. Two of the piles tested up to 2.5*WL in Site D also demonstrate that the geotechnical capacity of the pile is more than 2.5*WL as the residual settlement after unloading from the maximum test load is relatively small (5.48mm and 6.33mm respectively).

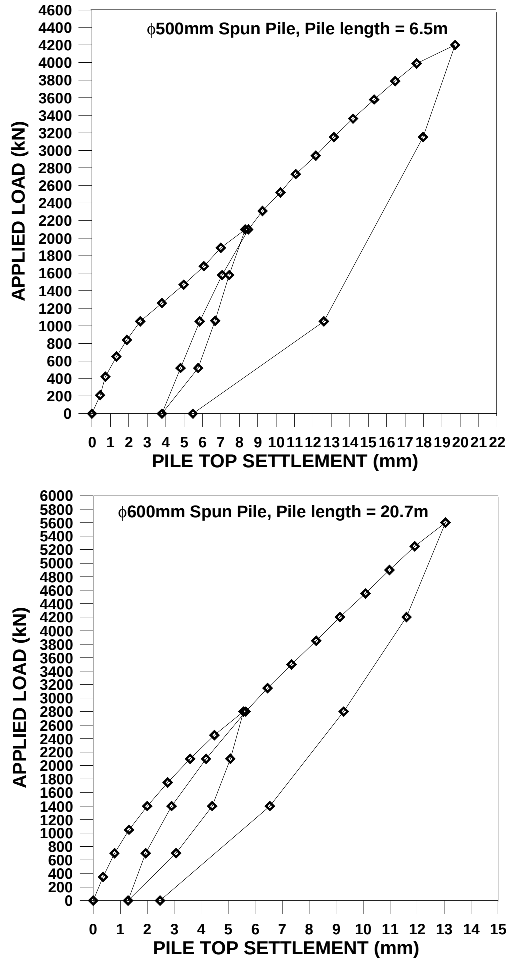


Figure 3 Load-settlement curve for pile static load tests at Site B.

## 3. RECOMMENDED TERMINATION CRITERION FOR JACK-IN PILES INSTALLATION IN WEATHERED GRANITE

Based on the above case histories where the performance of the jack-in pile foundation is satisfactory with all the piles tested achieving a minimum of two times the pile working load, the recommended termination criterion for jack-in piles in weathered granite formation are as follows:

*"The termination criterion is to jack the pile to 2.0 times of the design load for a minimum of two cycles. The corresponding pressure has to be held for minimum 30 seconds with settlement not exceeding 2mm."*

Questions often arise with regards to the adequacy of maintaining the jack-in pressure for the relatively short duration of 30-seconds only where long-term settlement of the pile cannot be verified. However, it should be noted that the objective of specifying the termination criterion is to ensure the pile is installed to the required bearing stratum in order to achieve the required geotechnical capacity and is not for settlement verification. This is similar to installation of driven piles where the termination (or "set") criterion of piles is determined to ensure adequate geotechnical capacity and long-term settlement of the piles definitely cannot be assessed during pile driving. For bored piles, verification of pile capacity and settlement characteristics depends solely on load tests.

The designer is still responsible for assessing the adequacy of the installed pile length based on available subsurface investigation (SI) information. For example, achieving the required termination criterion on a thin layer of intermediate hard layer/boulder which is followed by very soft soil below it is not adequate for piles where significant proportion of its capacity consists of end-bearing resistance. The pile should terminate in a competent stratum to ensure the load-carrying capacity of the pile is adequate in the long-term within acceptable serviceability limits. This is similar to conventional driven piles design practice. Therefore, similar to conventional pile design, the termination criterion for jack-in piles should be subjected to verification via maintained load tests to ensure adequate geotechnical capacity within acceptable serviceability limits.

## 4. MOBILISED SHAFT FRICTION AND END-BEARING RESISTANCE OF JACK-IN PILES

Preliminary instrumented test piles were also carried out at Site C (3 Nos.) and Site D (2 Nos.) in order to measure the mobilised shaft friction and end-bearing resistance of the jack-in piles. The piles were instrumented using the Global Strain Extensometer (GLOSTREXT) system (Krishnan & Lee, 2006). Figures 4 and 5 show the load transfer curve for shaft friction and end-bearing for PTP-3 (Site C) and PTP-1 (Site D) respectively.

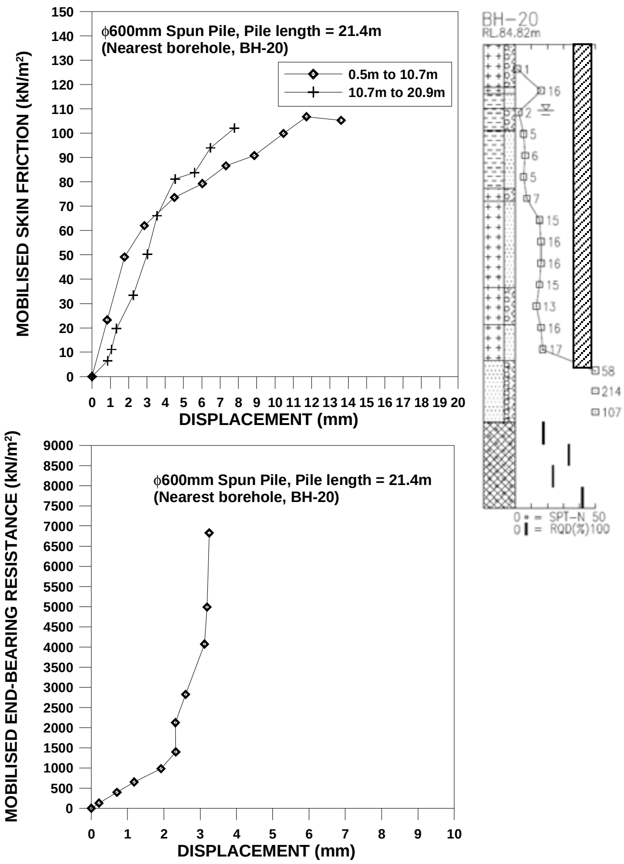


Figure 4 Mobilised shaft friction and end-bearing resistance for PTP-3 (Site C)-Borehole profile relevant to test pile also shown.

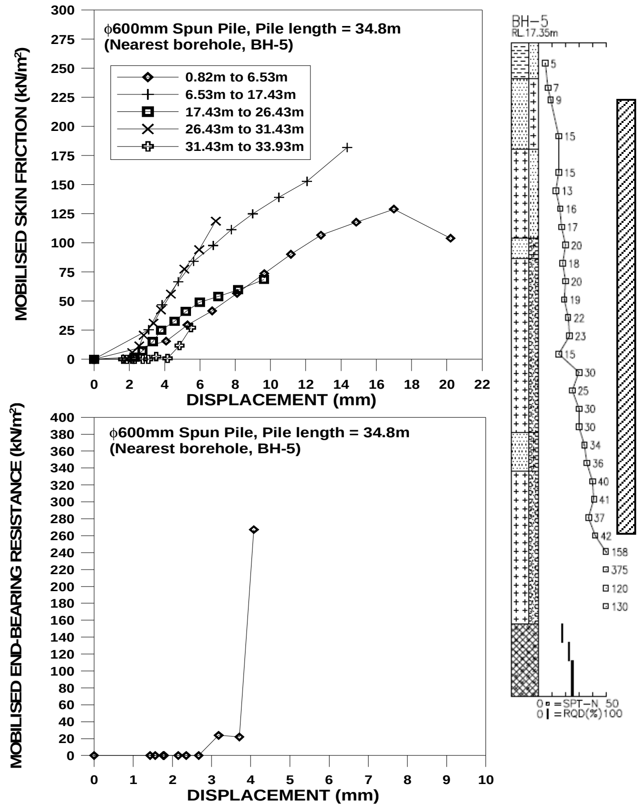


Figure 5 Mobilised shaft friction and end-bearing resistance for PTP-1 (Site D)-Borehole profile relevant to test pile also shown.

From the figures, the following observations can be made:

a) The pile base exhibits stiff response where significant end-bearing is mobilised at relatively small settlement. This is expected due to the precompression of the soil at the base during pile installation and also due to the effect of residual load.

b) Most of the shaft friction and end-bearing resistance have not reached the ultimate value even at two times working load. This indicates that the ultimate capacity of the pile is higher than two times working load.

c) Based on the nearest boreholes to the test piles, the shaft friction generally exceeds 5*SPT-N (in kPa) and in one extreme result, the value is approximately 20*SPT-N. No meaningful correlations for end-bearing resistance can be derived as the base movement is relatively small to mobilise the ultimate end-bearing resistance.

## 5. CONCLUSION

Performance of jack-in piles in weathered granite is presented based on static load test results. Based on the test results, termination criterion of jacking force to two times pile working load and holding time of 30-seconds (two cycles) with settlement not exceeding 2mm is satisfactory. Preliminary results obtained from instrumented test pile results indicate that conservative estimate of shaft friction for jack-in piles in weathered granite is approximately 5*SPT-N (in kPa).

## 6. REFERENCES

[1] Krishnan, S. & Lee, S.K., “A novel approach to the performance evaluation of driven prestressed concrete piles and bored cast-in-place piles”, Proc. 10th Int. Conf. On Piling and Deep Foundations, Amsterdam, 2006.