

## Good Practice for Installation of Jacked Foundation Piles in Singapore



### Working Group on Jacked Foundation Pile

Chairman	:	Er. Poh Chee Kuan	-	Geotechnical Society of Singapore
Member :		Er. Chua Tong Seng	-	Geotechnical Society of Singapore
		Er. Dr. Ng Tiong Guan	-	Geotechnical Society of Singapore
		Er. Dr. Yet Nai Song	-	Building and Construction Authority
		Er. Chua Kok Eng	-	Housing and Development Board
		Dr Jeyatharan Kumarasamy	-	Land Transport Authority
		Prof. Leung Chun Fai	-	National University of Singapore
		Prof. Dr. Ting Seng Kiong	-	Singapore Institute of Technology
		Er. Dr. Ganeshan Vallipuram	-	AECOM Singapore
		Er. Gwee Boon Hong	-	CSC Holdings Limited
		Er. Jimmy Lim	-	Individual capacity
		Er. Song Wee Ngee	-	KTP Consultants Pte Ltd
		Er. Foo Hee Kang	-	Resource Piling Pte Ltd
		Mr. Ong Tiong Siew	-	Ryobi Kiso Pte Ltd
		Mr. Eric Low	-	Zap Piling Pte Ltd



## **1. Background**

Jacked piling is a piling method using pre-formed pile (e.g. prestressed concrete spun pile, precast RC piles, H-steel piles, etc.) pressed into the ground by utilizing a hydraulic jacking system working against a set of dead weight (preferably steel blocks but can be concrete blocks). It is an environmentally friendly method which is vibration free, air pollution free and having low noise level.

Singapore has got about 20 years history of utilizing jacked piling and the market has machines of jacking capacity of up to 800 tonnes. It is recommended that the machine to be used up to about 75% of its maximum capacity. In Singapore, the method began with installation of small size, low capacity piles. Currently, the market has more track records of bigger size, higher capacity piles (e.g. 600 mm dia. Spun piles).

Besides the mentioned friendly characteristics, the method also has advantages of superior verticality of pile, high machine stability, elimination of the risk of working from height and performing some forms of load testing on every pile during its installation.

## **2. Installation and Termination Criteria of Jacked Piles in Singapore**

### **2.1 Termination criterion of jacked piles**

In the design stage, the designer will compute the required pile penetration based on SI boreholes data and assumed skin friction and end bearing resistance. He then specifies the required pile penetration on the drawing. Some designers will specify this computed penetration depth as the minimum penetration depth on the drawing. Most designers in Singapore, however, will also specify the required jacking force and set criterion on the piling plan. This is normally called the pile termination criterion for jacked pile.

### **2.2 Magnitude of jacked force and set criterion**

Magnitude of jacked force required for installation of jacked pile is related to the ultimate geotechnical capacity required which is normally 2.5 times working load. In Singapore, where the general experience in the ultimate geotechnical capacity of the pile,  $P_u$ , exceeds the pile load jacking,  $P_j$ , literature review documenting the relationship is either scanty or absent. Based on research work



carried out in Hong Kong, (Zhang et.al, 2006), it has been reported that ultimate geotechnical capacity of jacked piles,  $P_u$  can range from 0.8  $P_j$  to 1.2  $P_j$ ; and that  $P_u$  is less than  $P_j$  when the pile depth is less than 37 times the pile diameter. In Singapore, the pile is normally jacked into the ground with a jacked force,  $P_j$ , adjusted in steps to a value of 2 to 2.5 WL. Jacking is continued until practical refusal is reached. The  $P_j$  is then released to zero and subsequently re-applied (without pause). The downwards movement of the pile between the virgin jack (before release) and the re-jack (before release) is measured and it is considered the first 'set'. The release and re-jack is again performed to obtain the 2<sup>nd</sup> 'set'. The measured movement is checked against 'set' criteria. The pile is considered 'set' if the downwards movement is not exceeding 5 mm with a holding time of min 30 seconds. If the downwards movement is more than the specified limit, the release and re-jack process is repeated until the 'set' criteria as determined by the engineer is achieved. Two consistent 'sets' are recommended. The designer who bears the design responsibility should decide on the 'set' criteria, and should take into consideration the type and sensitivity of the structures supported by the piles, the slenderness ratio, creep, etc. In Hong Kong (Zhang, 2007), the set criteria is taken as 5mm settlement per 15 minutes; whereas in Malaysia (Gue and Chow, 2009), some consultants specify 2mm settlement limit for a minimum holding duration of 30 seconds.

Termination criterion pre-determined by the designer should be subject to verification by the maintained load test. Termination criterion should be revised if the maintained load test carried out at the specific project site fails to verify it. The termination criterion also need to consider 2 important aspects commonly encountered at site:

- (i) If the pile cut-off-level is significantly below the ground level, the skin friction from ground level to cut-off level could be significant and should be added into the jack in load,  $P_j$ .
- (ii) If the pile is penetrating through a consolidating soft soil layer, the consolidating soil layer which contributes to positive shaft resistance during jacking will exert a downdrag force to become negative skin friction in the long term. This reversal of the direction of force has to be considered in the magnitude of jacked load,  $P_j$ , during installation.

### **3.0 Good Practice in the Installation of Jacked Piles**

In the installation process, the pile is checked on its verticality and welding is generally carried out to join a number of pile sections.



Being a type of displacement piles, the design and execution of jacked piles have to comply with the requirements of Eurocode 7.

Additional good practices are (included but not limited to):

- a. The pile should not have its alignment adjusted by force during installation
- b. For bigger pile group, jacked sequence is recommended to be from inside out or in certain direction such as left to right.
- c. If the pile termination criterion has been reached but the pile depth is grossly shorter than the design depth, the designer will assess and determine whether the pile can be terminated at the shallower depth. However, if the depth is more than 20% shorter than the depth shown on the approved piling plan, it is considered major deviation and the designer has to submit amendment plan for approval. For cases where as-built pile depth is shorter than the depth shown in the approved drawing by more than 20%, the designer shall determine and substantiate whether it is necessary to conduct additional load tests to verify the capacity of the shorter piles.
- d. If the pile designed depth has been reached at site but the pile termination criterion has still not yet been attained, it could mean that the soil at the pile location is locally poorer than what is revealed by the SI borehole. In such scenario, piling should continue until the pile termination criterion is reached. The designer may redesign to have the pile capacity downgraded in order to comply with the termination criteria.
- e. The load cells which are used to measure  $P_j$  must be calibrated by an accredited laboratory before the first jack at each site, i.e. in between commencements of two piling projects, or 6 months, whichever is shorter.
- f. Shorter piles are more likely to experience heave due to the installation of adjacent piles. When a pile heaves, its geotechnical capacity is likely to be adversely affected. In situation where piles are likely to experience upheaval, the top portion of piles can have some forms of reference to enable survey of the possible upheaval (at certain percentage of piles in relevant location). When required, a re-jacking shall be carried out for upheaval piles.
- g. When a pile is short,  $P_j$  is recommended to be of higher value and the pile toe to be installed with a shoe so as to gain greater penetration to reduce the risk of excessive settlement as more resistance is derived from the end bearing. The designer should review  $P_j$  when this situation arises or may consider some degrees of downgrading especially when upheaval has occurred.



- h. When a pile is long and upheaval is found or expected,  $P_j$  may be of higher value and the designer may require the skin resistance of the pile to be min. 1.5 WL or may downgrade the pile capacity based on the magnitude of upheaval. The designer is recommended to review  $P_j$  when this situation arises.
- l. Using of heavier jacked machine for maintained pile load test may be workable if the requirements of maintained load test as stipulated in the relevant code could be fulfilled. This includes the following: (a) The load should be measured by a calibrated load gauge and also by a calibrated pressure gauge; (b) the nearest edge of the of the crib supporting the jacked machine should not be closer than 2.5 times pile diameter to the surface of the test pile; (c) The test set-up should be capable of measuring the pile settlement to an accuracy of 0.1mm and the reference frame should not be affected by the test loading or other operations at site; (d) the maintained duration of the applied load should be long enough to achieve a rate of movement of less than 0.25mm/hr per each increment of load. This method is likely to be productive and save a lot of labour and time.
- j. When more than one jacked machine are working on site, try not to cluster the machines at closed distance to each other as that will cause greater ground movements.
- k. As the jacked machine can be very heavy, platform needs to be of higher quality especially in terms of compaction and site drainage.
- l. Use of dolly is acceptable as long as the pile should be aimed to set with its top above the cut off level and the performance of piles so installed is verified by working load tests.
- m. The magnitude of jacked force at every 0.5m to 1.0m penetration can be recorded.

#### **4. Protective Measures**

Jacked piling has been reported to cause damage to adjacent buildings and structures, particularly in landed development where adjacent structures are located in close proximity. When this happens, work will be stopped while engineer explore on rectification proposal. This will result in delay to the project and hamper the construction productivity. Furthermore, there may be costly compensation involved. To reduce adverse impact caused by jacked piling on neighbouring buildings and structures, the designer has to determine what protective measures are needed and specify them on the piling plan for implementation by the piling contractor. The protective measures can include the following:

- (a) Relief wells around the pile point or at strategic sides next to the piling area;
- (b) Pre-boring at the pile point;
- (c) Monitoring the ground movement and building movement during piling work;
- (d) Where there is a sensitive adjacent structure, install a temporary earth retaining wall to contain the ground movement within the project boundary;
- (e) Conduct a trial on the first pile installation and observe the performance.
- (f) Installation of an opened trench.

#### 4.1 Relief wells

In terms of ground movement control, relief wells are recommended to be installed at strategic locations such as at boundary next to the neighbouring structures or services. The wells are generally 400 mm to 600 mm dia. bored holes. If the soil is collapsible, perforated casing is inserted for stabilization of holes and enabling displaced soil to enter the holes. The relief wells have to be maintained from time to time.



Figure 1. Perforated steel pipes used as relief well

The photograph above (Figure 1) shows 400mm diameter perforated steel pipes used as relief wells in a jacked piling project in Singapore. Holes are regularly spaced around the circumference and along the entire pipe length. The pipe has a depth of 15 m. It is reported to be effective to reduce the ground movement during jacked piling.

Uncased relief well stabilised by bentonite may not be suitable in jacked piling project. It has been reported that these uncased relief wells used in some projects had already collapsed due to movement of heavy jacked piling machinery on ground surface even prior to installation of the jacked piles. This not only defeats the purpose of relief wells but also creates undesirable settlement problem to adjacent structures before piling work commences.

#### 4.2 Pre-boring at pile point

Pre-boring at the pile point is recommended to further minimize ground movement up to certain depth (e.g. pre-boring to 12m if there is a nearby sewer line at 11m depth). The diameter of the hole is normally slightly smaller than the pile size to facilitate sinking of pile sections and ensure adequate shaft resistance. Prudence should be exercised to ensure that the pre-bore hole is stable before the insertion of the pile section.

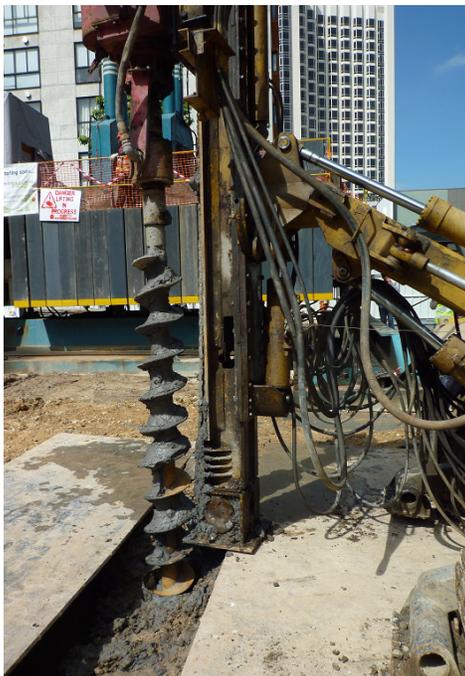


Figure 2. Machine (left) used to make pre –bore hole (right)

Photo above (Figure 2) shows the machine used to make pre-bore hole in one of the project in Singapore.

#### 4.3 Monitoring of ground movement during piling



Instruments normally used include settlement markers, inclinometers, tilt meters (on structures), crack meters (on structures). Monitoring of settlement of adjacent structures during jacked piling is of utmost importance. There must be adequate building settlement monitoring points and the frequency of monitoring should be adjusted in accordance to the piling rate. As a common industry practice, the adjacent buildings should not be allowed to settle or heave by more than 25mm in any case.

While ground movements need to be observed, ultimately it is the existing structures and services nearby that need protection. In setting limits, the designer should be familiar with the authority's requirements e.g. LTA's requirements.

### **5. Impact Assessment and Highly Unfavourable Conditions for Displacement Piles including Jacked Piles**

As jacked piling is a displacement method of piling, emphasis should be placed on the possible adverse impact of this piling method on adjacent structures and buildings. At design stage, the engineer has to carry out feasibility study to assess the suitability of the displacement piling method with relevance to sensitivity and proximity of adjacent buildings and taking the ground condition into consideration. Based on the impact assessment study, the designer will determine what precautionary measures are needed to prevent damage to adjacent buildings and indicate these measures on the piling drawings to be implemented during piling work.

At design stage, the designer should identify all unfavourable conditions existing in a piling project site. These unfavourable conditions for displacement piling work include:

a) **High density of displacement piles in a project site**

The density of displacement piles in a site is high when many large and long piles are installed into the ground. The larger the volume of piles inserted into ground for a specific site area, the larger is its density and the more unfavourable is its impact on existing adjacent structures and services.

b) **The ground which is underlain by thick deposit of soft clay**

When the underlying soft clay is thick (like soft marine clay up to 30 m deep), the piles will be long. Consequently, there will be more ground displacement and this is aggravated by the



presence of thick soft clay layer which will migrate towards neighbouring buildings and may affect their foundation.

**c) Adjacent buildings are located in close proximity to the piling location**

Buildings are normally located close to one other in landed development. The closer the adjacent buildings, the larger is the impact of displacement piling work. The influence zone of displacement piling work is a function of pile length. Adjacent buildings located within the influence zone of displacement piling are likely to be affected by the work.

**d) Adjacent buildings are sensitive to ground movements**

Existing buildings supported on footing and with underlying soft clay are very sensitive to ground movement arising from displacement piling work. Extra prudence is needed if piling has to be carried out near to these sensitive buildings.

**e) The weight of the jacked pile machine**

In displacement piling, one significant difference between jacked piling and driven piling is in the weight of the piling machine. A jacked machine can be many times heavier than a driven machine. The sheer weight of the jacked machine is likely to 'push' the soil in a stronger manner and as a consequence, causes a bigger magnitude of soil movements in addition to the soil displaced due to the pile body. That will possibly result in excessive pile eccentricities and damages to the surrounding structures and services especially when a large 'void' is located next to the piling area e.g. a canal.

When many of the above unfavourable conditions are co-existing in a project site, the risk of causing damage to the neighbouring properties is high, great prudence need to be exercised if displacement piles are to be used. In highly unfavourable conditions like the use of large number of large and long piles penetrating through a thick underlying soft marine clay (e.g. 30m deep) in landed development where adjacent buildings are located in very close proximity and are sensitive to movement, the usage of large displacement piling should be discouraged or avoided. The more favourable piling system in such case includes:

- (i) Non-displacement piles like bored piles or grouted micropiles;
- (ii) Small displacement piles, like steel H-piles (Figure 3).



Figure 3. Use of steel H-pile in a landed development site in Singapore.

### Acknowledgement

The working group would like to thank Prof Harry Tan of NUS, Er. Lauw SW of LSW Consulting Pte Ltd, Er. Chia WK of ARUP, Dr. Indra of Golder Associates and Er. Chong KS of IES and many others who have shared their valuable views in the preparation of this good practice guideline.

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