Noise and Vibration Monitoring for Silent Piling in Singapore

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ABSTRACT

Conventional dynamic pile driving has been commonly used to install sheet piles and foundation piles but this technique tends to generate excessive noise and ground vibration to the surroundings during piling. This research study aims to evaluate the noise and vibration arising from the use of different silent piling rigs in various soil conditions in Singapore. At one site, noise and vibration measurements were also made with vibro hammer to facilitate comparison of noise and vibration levels between silent piling and vibro piling at the same site. In addition, the measured values will be evaluated against the desired noise and vibration limits set by the Singapore authorities. The results of noise and vibration against distance will also be compared with those proposed predicted values using an existing method.

Key words: *Silent Piler, Vibratory, Percussion Hammer, Noise, Vibration*

1. Introduction

Silent piling has been employed to install sheet piles in soft to medium stiff soils in Singapore for many years, see for example Goh et al. (2004a, 2004b, 2004c, 2007). Recently, the more powerful Super Crush Piler has been successfully used to install sheet piles in stiff and hard soils in Singapore. Although silent piling is known to cause less noise and vibration levels as compared to conventional dynamic piling methods, there are relatively few reported case studies on comparing the noise and vibration levels due to silent piling versus conventional piling technique at the same site.

With a research grant from the International Press-in Association (IPA), a research study was embarked to evaluate the noise and vibration levels arising from the use of different piling rigs at several sites in Singapore. The present study focuses on the installation of sheet pile walls as the silent piling technique has been specified as the preferred method under certain scenarios by the Singapore developers and authorities. The results of the study are presented in detail in this paper.

2. Press-in piling method

The Press-in Piling Method is a non-dynamic piling method for installing continuous pre-formed piles. The technique uses hydraulic rams to push piles into the ground. This novel installation method has been presented as a ‘silent’ or ‘vibration-free’ piling method.

The present study focuses on the press-in method derived from the reaction principle. The size of press-in machine has to be massive if the reaction force is obtained solely from the machine weight. To develop a relatively small and compact lightweight machine which has the sufficient penetration force, shaft friction of previously installed piles is used, see **Fig. 1**.

In 1967, Mr Akio Kitamura founded Giken Seisakusho in Kochi, Japan to develop this idea. In 1975, the first press-in piling machine based on the reaction principle was produced. This press-in piling machine derives from a simple arrangement; gripping the previous installed piles to press-in subsequent piles. With such a simple systematic arrangement, the press-in piling machine can self-walk along the pile top. The press-in piling machines which are available in the construction site are better known as the 'Silent Piler', see **Fig. 2**.

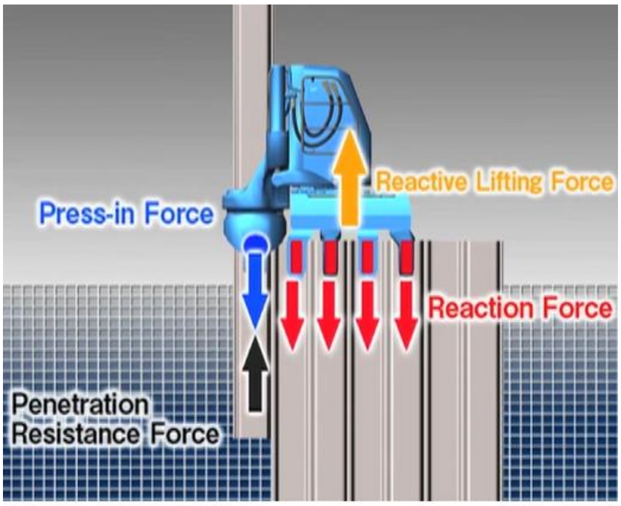


Fig. 1 Press-in piling based on reaction principle

Fig. 2 Press-in piling machine, known as "Silent Piler"

Each machine has a built-in load meter, accurately measuring the resistance as it pushes the pile. Hence, all pressed-in piles are proof-tested as the penetration resistance of each pile can be monitored directly during jacking. Guides are not necessary as the machine firmly grasps the installed piles and with visual assistance of a pile laser.

The execution of press-in work was initially very difficult because of the flimsiness of sheet piles at great depth. Furthermore, the formation of "pile plug" and "pressure bulb" has greatly affected the efficiency of the sheet piling works. These adverse factors have created a section greater than the pile itself and the penetration resistance increases during the press-in piling operation. The water jet system, which is supposed to lubricate the sheet pile and float the soil particles, has failed to perform its function effectively in such soil condition.

To tackle the limitation, the Super Crush System (SCU400M) has been developed. The Super Crush Piler was subsequently mobilized to assist the sheet piling works at Penang High Court. The fundamental difference using the Super Crush Piler is that this press-in machine has an integrated auguring tool (**Fig. 3**). This auguring tool is placed inside a steel casing attached to the press-in machine. Sheet pile which is abutted to the steel casing is rigid and this prevents the bending and twisting of sheet pile. This would ensure the sheet pile toe from deviating from the completion line.

Fig. 3 Sheet piles installed by Super Crush System

A case example for the use of silent piling in Singapore is presented as follows. The New Pandan Pumping Station and Pipelines Upgrading Works in Singapore have been initiated by the Public Utilities Board (PUB) as part of the Singapore Government Master Plan to increase the capacity of water storage in existing reservoirs (**Fig. 4**). The upgrading works involve constructing a new pumping station next to the existing Pandan Pumping Station and laying a new pipe parallel to the existing one. The water from Sungei Pandan River will be pumped at intervals into Pandan Reservoir using a 1.4m diameter pipeline which channeled through the reservoir dyke using the discharge outlet pipe.

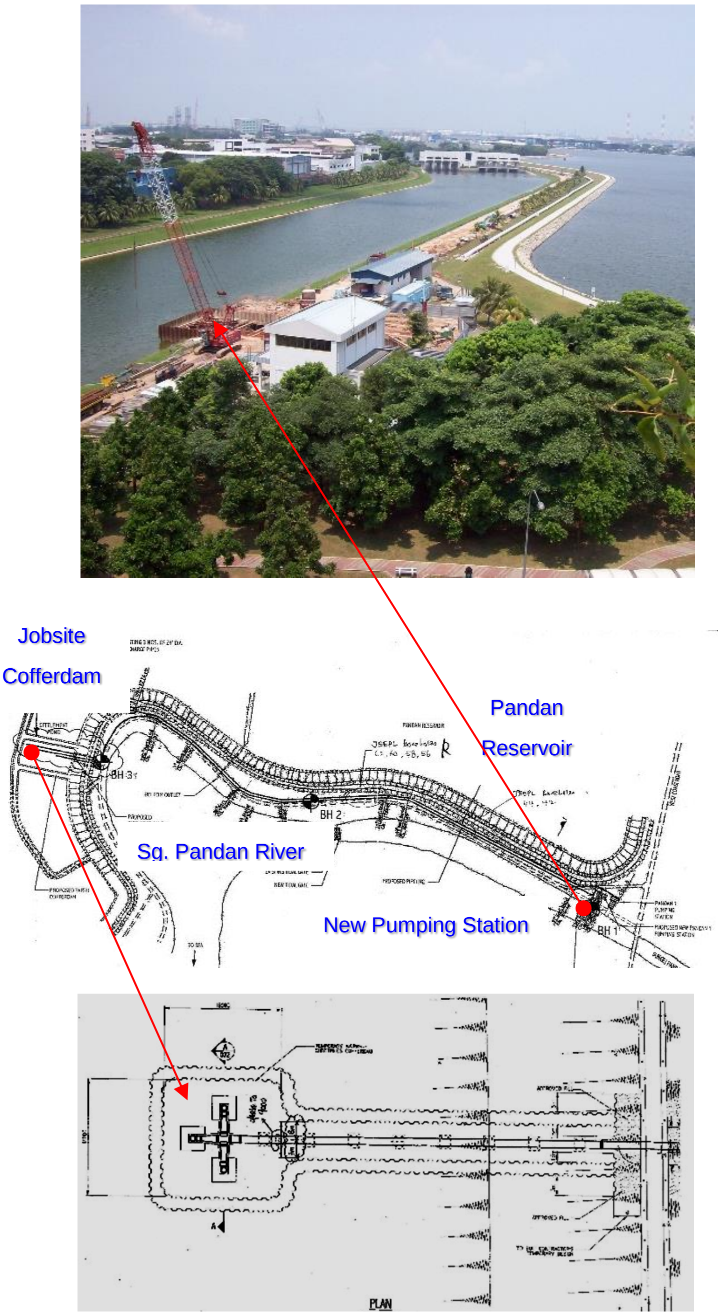


Fig. 4 Pumping station and discharge point

In this project, GIKEN Seisakusho Asia has been appointed as the specialist sub-contractor by a local main contractor (Koon Construction & Transport Co. Pte. Ltd.) to install over 1000 nos. of 18m sheet piles (Type FSP-IIIA) using the GRB Non-Staging Press-in Piling System. Two Silent Pilers (ECO100-4C and SA150), two Clamp Cranes (CB1A and CB1-7) and one pile transporter (TB3) have been employed (**Figs. 5 & 6**).

Based on the soil investigation report, soft clay is found for the first 12m below the water level. At greater depth of 15m, the soil becomes stiffer with standard penetration resistance SPT N value ranging from 30 to 50. The deepest water level is about 6m, which is located towards the centre of the reservoir. The penetration of sheet piles is assisted by the water jetting system. Average productivity is about 8-12 pieces per day with one vertical joint. The project was completed in 3 months in 2006.

Fig. 5 Giken Reaction Base (GRB) machineries

Fig. 6 Non-staging press-in piling (GRB System)

3. Noise and vibration limits in Singapore

In the early days, Singapore adopted the British Standard (BS5228, 1974) as the noise and vibration control for piling operation. Subsequently it issued its own regulations on noise and vibration limits. In 2007, the National Environment Agency (NEA) of Singapore issued guidelines on the maximum permissible construction noise levels in Singapore. **Table 1** shows the desired limiting values for various types of buildings at different times from Mondays to Saturdays. As expected, sensitive buildings such as hospitals and schools have the most stringent limits followed by residential buildings. The Sunday limiting values are similar except with more stringent limits for residential housing to enable residents to have a more peaceful rest on Sundays.

Table 1. NEA construction noise limits on or after 1st October 2007 (Mondays to Saturdays)

Types of affected buildings	7am – 7pm	7pm – 10pm	10pm – 7am
Hospital, schools, institutions of higher learning, homes for aged sick, etc	60 dBA (Leq 12 hrs)	50 dBA (Leq 12 hrs)	
	75 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)	
Residential buildings located less than 150m from the construction site	75 dBA (Leq 12 hrs)	65 dBA (Leq 1 hr)	-
	90 dBA (Leq 5 mins)	70 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)
Other buildings	75 dBA (Leq 12 hrs)	65 dBA (Leq 12 hrs)	
	90 dBA (Leq 5 mins)	70 dBA (Leq 5 mins)	

On vibration levels due to construction, Singapore authorities generally require vibration measurements of under 5 mm/s for residential buildings and 3 mm/s for sensitive buildings such as hospitals in order not to cause discomfort and probable damage to structures. To encourage quieter construction, NEA (2017) recently updated its guidelines for quieter construction and provided financial support to encourage contractors to reduce their noise and vibrations during construction using appropriate construction equipment and techniques.

4. Noise and Vibration Measurement Equipment

To support the present research, a Singapore company, Absolute Instrument Systems (Pte.) Ltd., has kindly loaned out their noise and vibration measurement devices and provided training and guidance to the university students on the correct use of the devices and sound interpretation of the measured data. **Fig. 7**(a) and (b) show the noise and vibration measurement device, respectively. The noise measurements are relatively straightforward but one must take note that L_{Aeq} 5 minute is the most important measurement parameter where L_{Aeq} is the equivalent continuous A-weighted sound pressure level and A-weighted sound emphasis on sound frequency from 20 Hz to 20 kHz. **Fig. 8** shows the raw data of noise measurements while **Fig. 9** shows the interpreted L_{Aeq} 5 minute results.

(a) (b)

Fig. 7 (a) Svantek 917 noise measurement device, (b) Instantel Micromate vibration monitor and receiver

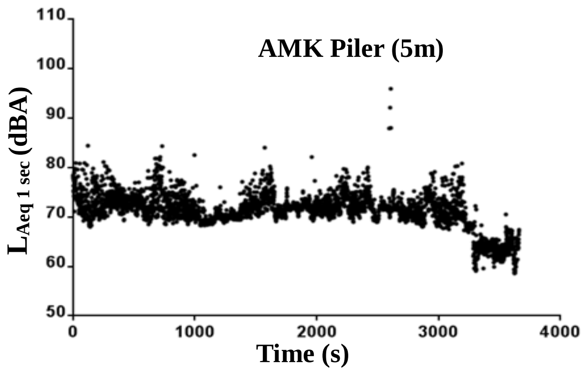


Fig. 8 Raw noise measurement data

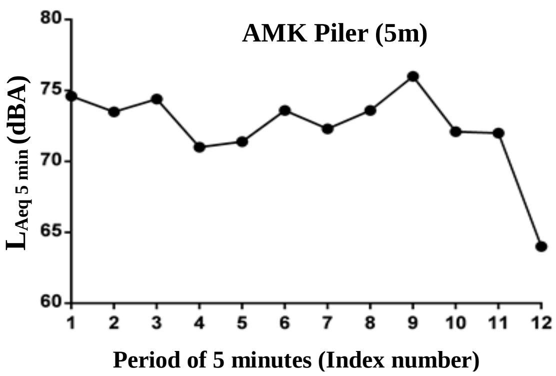


Fig. 9 Interpreted L_{Aeq} results

The vibration measurements and interpretations are less straightforward as there are large fluctuations in readings and hence possible misinterpretations of field data. **Fig. 10** shows the recorded raw vibration data which need to filtered to obtain the correct vibration measurements. The correct interpretations of data require proper training and experience.

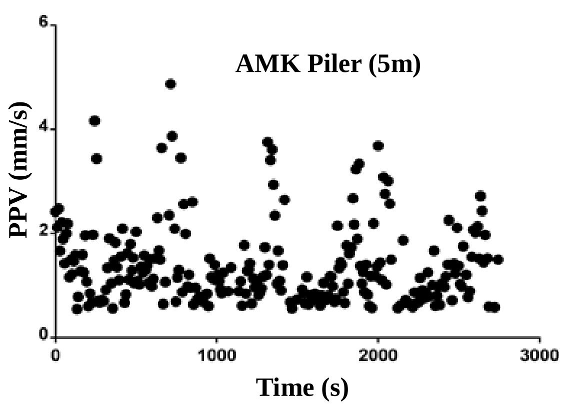


Fig. 10 Raw vibration measurement data

5. Case Studies

Noise and vibration measurements were made at 5 locations in Singapore. Four sites have subsurface profile comprising residual soils of sedimentary origin and weak sedimentary rocks locally known as the Jurong Formation. The standard penetration resistance SPT N values of the soils/rocks range from 2 to over 100. Silent piling was employed at all the 5 sites. For one site, noise and vibration measurements were also made on sheet piles installed by vibro hammer and crush piler, see **Fig. 11**. One site has soil profile of old alluvium and marine clay with SPT N values ranging from 1 to 28. The sheet pile penetration depth ranged from 13m to 24m at the 5 sites.

Two issues are worth mentioning. At certain sites, the noise levels due to the power source (**Fig. 12**) can be as severe as or even more severe than that due to silent piling. It is thus worth investigating on the reduction of noise level of the power source. In addition, the traffic noise at some sites can be as severe as that of piling and this factor is beyond the control of the construction personnel.

Fig. 11 Crush Piler

6. Interpretation of Noise Measurements Versus Distance From Source

The test results obtained from the sites are given in **Fig. 13** with the noise L_{Aeq} 5 minutes (dBA) plotted against distance from source. For all cases, the noise reduces with increasing distance from the source, as expected. At one site, the background welding noise is found to interfere with the measurements. The readings due to Power Pack are also provided in **Fig. 13** as a comparison.

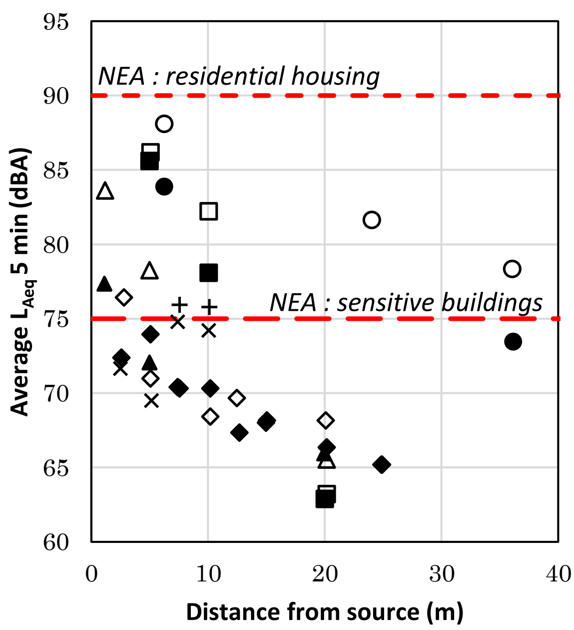
Fig. 12 Power pack

For the site with the deployment of vibro hammer, it is evident that the reduction of noise level with distance from source is not as good as that compared to silent piling. Although the noise due to silent piling is severe when it is close to the source, the noise reduces significantly and below the desired 75 dBA value at just 5m from the source. By and large, **Fig. 13** demonstrates that silent piling is more effective in reducing the noise levels during piling as compared to vibro hammer.

The above is even more evident if the noise measurements are plotted against logarithm of distance from source, see **Fig. 14**. As such, one must also pay appropriate attention to the effects of noise generated by Power Pack and other background noises to check whether they are the dominant noise source rather than the noise due to piling.

7. Interpretations of Vibration Measurements Versus Distance from Source

The vibration measurements are interpreted as peak particle velocity PPV and the results obtained from the 5 sites (some sites with limited data) are plotted against distance from source as shown in **Fig. 15**. As mentioned before, the raw data need to be filtered such that the correct vibration data can be deduced. The desired limits of 5 mm/s for residential buildings and 3 mm/s for sensitive buildings as well as data from existing studies are also marked in the figure. It is evident that vibro hammer created much larger vibration levels as compared those due to silent piling for the 5 sites.



Symbol	Location	Piler
○	Rockaway park	Vibro 120ft depth
●		Vibro 60ft depth
□	T220	Vibro 1st day
■		Vibro 2nd day
△	AMK	Power pack
▲		Piler
◇	T222	Piler
◆		Auger
X	Leonie	2nd extraction
+		Background welding noise

Fig. 13 Plot of noise level represented by average L_{Aeq} 5 min versus distance from source

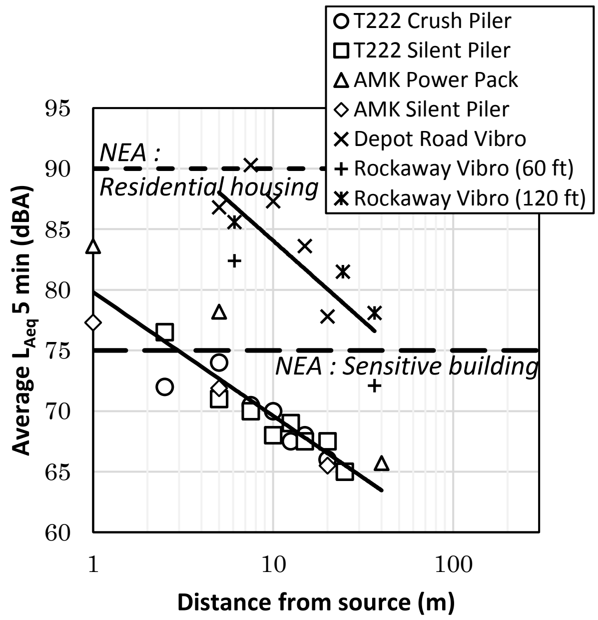


Fig. 14 Plot of L_{Aeq} 5 min versus logarithm of distance from Source

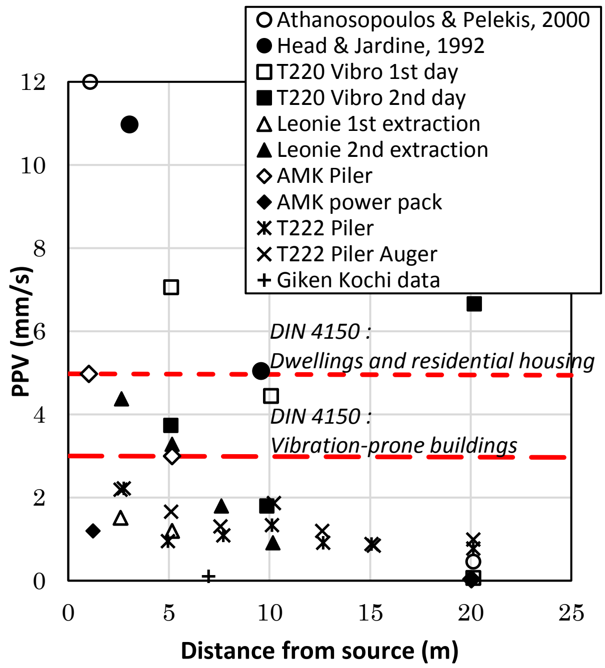


Fig. 15 Vibration level versus distance from source

Many researchers from outside Singapore had carried out research on the effects of piling on noise and vibration. These include the studies by Roger and Littlejohn (1980), Head and Jardine (1992), Selby (1997) and White et al. (2002). In the present study, the proposed simple correlation between vibration levels with distance from source from the study by White et al. (2002) is evaluated.

To evaluate the measured data against the above mentioned correlation, the plot of PPV versus log of distance from source is presented in **Fig. 16**. It appears that the formulation presented by White et al. (2002) may not be applicable to Singapore soils. In general, White's formulation over-predicts the vibration level close to the source while under predicts the vibration level away from the source. The latter may not be conservative for Singapore soil conditions and may result in the under-prediction of vibration level at some distance from the source. As limited data are available in the present study, further studies are clearly needed to further investigate the issue.

Based on the observed vibration measurements against distance from source shown in **Fig. 16**, the following revised empirical correlation of vibration level PPV for press-in silent piling for Singapore soils, $PPV_{press\text{-}in}$ is proposed:

$$PPV_{press\text{-}in} \text{ (in mm/s)} = 4/(r^{0.4}) \qquad (1)$$

where r is the distance from the source in m. If the desired vibration limit PPV = 3 mm/s for sensitive buildings, then a minimum distance of 2 m is desired which is not significant in practice. More case studies should be carried out to further verify the above formulation

8. Concluding Remarks

Conventional dynamic piling methods are ill-suited to the urban environment. The press-in method offers an alternative technique of pile installation, which allows pre-formed piles to be installed with minimal noise and vibration. Field measurements of noise and ground vibrations during press-in piling at 5 Singapore sites are presented. It is evident that silent piling can effectively reduce the noise and vibration levels to within the desired limits set by the authorities at a relatively short distance from the source of piling. Based on this initial database, preliminary prediction formulation are presented in this paper. The correlation is not the same as those predicted using an established method revealing that the latter may not be applicable to Singapore soil conditions. Equipped with these tools, designers can assess the relative environmental impact of each installation method when planning piling works. Further study should be conducted to verify the formulation proposed in the present study.

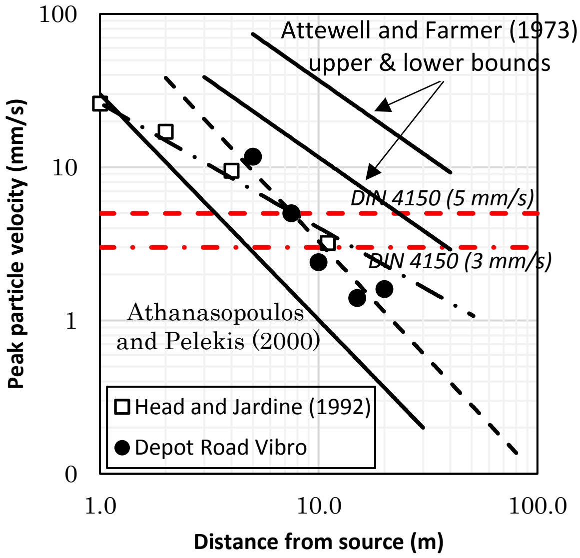


Fig. 16 Plot of vibration level versus logarithm of distance from source

9. Acknowledgements

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