Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Nailing a deep excavation in soft soil with jacked in pipe inclusions

Cheang Wai Lum, Tan Siew Ann, Yong Kwet Yew & Ganeswara R. Dasari
Department of Civil Engineering, National University of Singapore, Singapore

ABSTRACT: This paper briefly describes the use of jacked-in pipes in soft clayey soils. The pipe reinforcement functions as a temporary internal support system, working in combination with contiguous bored pile walls for the excavation of a 3-1/2 storey deep car park basement. The pipes were open-ended and it was significantly plugged when it was jacked to its design length. It was found that nail set-up was a contributing factor in the increased in axial resistance of the nail inclusions due to compaction and reconsolidation of the disturbed soil.

This hybrid retaining system is a departure from the conventional technique of soil nailing, in which a stiff cast in-situ wall was used in conjunction with soil nails. Geotechnical field instrumentation data indicated that the contiguous bored pile wall exhibits restrained cantilever deflection profiles and this can be attributed to the pipe nails in changing the strain field and arresting strains due to soil stress relief.

Finite element analyses were performed and compared with instrumented field results in an attempt to study the possible working mechanisms. Parametric studies were made to investigate the interplay between nail, soil and structure.

This project shows that soil nailing in conjunction with a stiff structural facing in soft clayey soils is possible, at least for short term and can be effectively used as temporary support in deep excavation.

1 INTRODUCTION

Deep basement construction is becoming increasingly expensive, nullifying the justification for over-conservative designs. One such solution where construction cost can be reduced is by employing fast and cost-effective deep basement construction techniques. This paper will highlight a hybrid construction method where the science and art of soil nailing was used in conjunction with an embedded cast in-situ wall for the stabilisation of a deep excavation.

Geotechnical field instrumentation has proven to be a valuable tool in assessing the validity of initial design assumptions and assessing the overall performance of this hybrid support system.

Soil nailing is an in-situ soil reinforcement technique, which in the last three decades has been successfully used in Europe and more recently in South-east Asia.

To this extend, various installation methods have been invented and innovated all with the intention of improving the versatility and adaptability of this technique in difficult ground conditions.

The method of reinforcing a mass of soil with pipe inclusions by jacking was first conceived in an excavation project in Malaysia. The first successful use of this technique was reported by Cheang et.al.,1999 and subsequently by Liew et al., 2000.

The later case history is of interest as this technique was used in soft clayey soil conditions and it is the subject and focus of another paper published in this conference by the second author of this paper (Tan et al. 2001).

2 CASE HISTORY AND FIELD DATA

2.1 *The jack-in technique*

It has been said that necessity is the mother of all inventions and how true this statement holds as the aforementioned method of nail installation was conceived by a group of engineers faced with the problem of stabilising a deep excavation in soft soil conditions and high water table.

The conventional technique of nail installation was initially used, but due to very difficult site conditions of soft ground and collapsing boreholes this method was discarded and it was envisioned that a method which does not involves drill-and-grout and speedier nail construction will stand a better chance in such hostile conditions.

Figure 1. Contiguous bored pile wall supported by nails.

Figure 2a. Jack-in in progress.

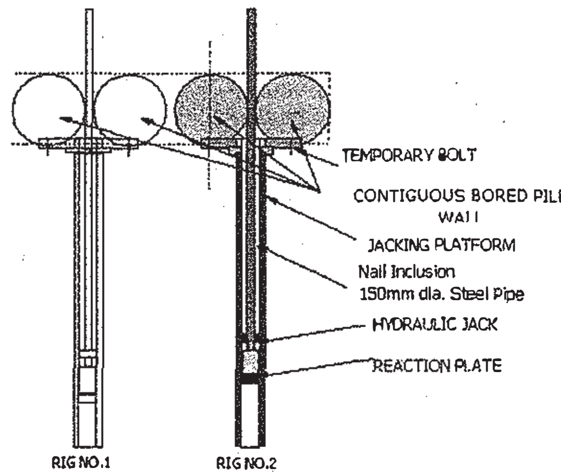

Figure 2b. Schematic of jack-in rig working in tandem

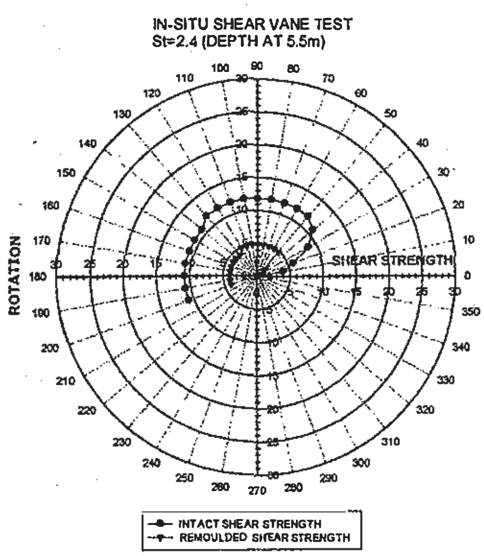

Figure 3a. In-situ vane shear at 5.5m (p'=45kPa)

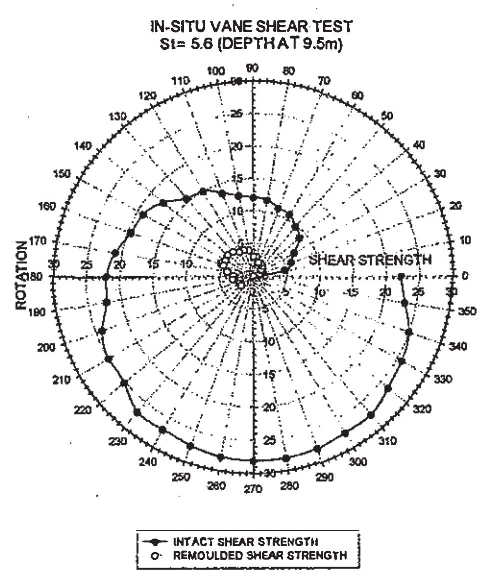

Figure 3b. In-situ vane shear at 9.5m (p'=76kPa)

Therefore the jack-in technique or better known as *jack-in anchors*[1] was invented. This method of installation is relatively cheap compared to other modes of installation as the passive nail inclusions are made of easily obtainable mild steel pipes. In the USJ-19 project pipes of 12m lengths with an outer and inner diameter of 150mm and 140mm respectively were used. The installation rig as shown in Figure 1 is constructed from a single length `H' structural steel section and welded with `U' shape stiffener plates located at strategic intervals depending on the maximum stroke of a single jack. These plates will function as reaction devices during the jacking process. Due to its low fabricating cost, multiple jacking rigs can be mobilised, therefore the amount of time a particular excavation phase is left unsupported will be decreased and this directly will decrease the construction period. In the USJ-19 deep excavation (Cheang et al., 1999) more than ten jacking rigs were employed.

A significant advantage of the jack-in technique is that the during the penetration process, the pressure of the jacks and the time needed to insert a particular length of nail (the nails were marked in lm spacing) can be monitored. This enables the strength and stiffness of the in-situ soil to be roughly estimated and ascertain. With further analytical investigation, the strength and stiffness of the soil can be correlated to jack pressure and penetration rate.

2.2 *Jack-in nail inclusions in soft tropical residual soil - The effects of installation and subsequent consolidation*

The interfacial resistance of soil nails is govern by the magnitude of effective radial stress. In-situ pullout out test perform right after the installation process yielded very low pullout capacity of about 25kN on average which corresponds to a unit resistance of 5kpa with variation occurring depending on the local soil condition and overburden pressure. In-situ vane shear test results (Figures 3a and b) indicated that the normalised intact shear strength (Su/p') as shown in Figure 4, was about 0.15 (Average Su =20kPa, Range =12 ~ 28 kPa) and the remoulded shear strength as shown in Figure 5, was on average 5kpa (4.8 ~6.0 kPa). This indicated that the soil stress state at the periphery of the nail face after installa

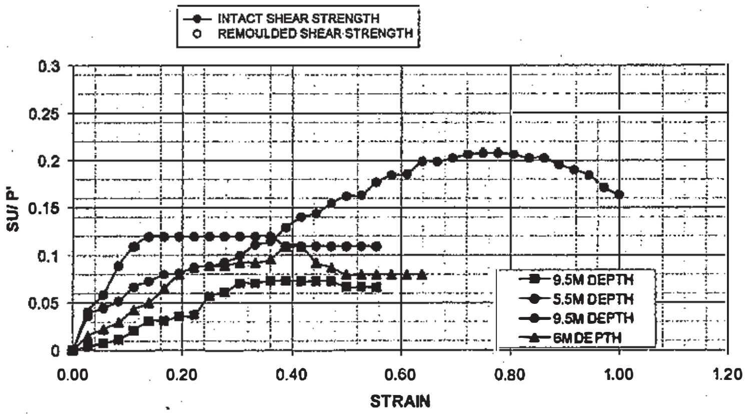

Figure 4. Normalised intact shear strength.

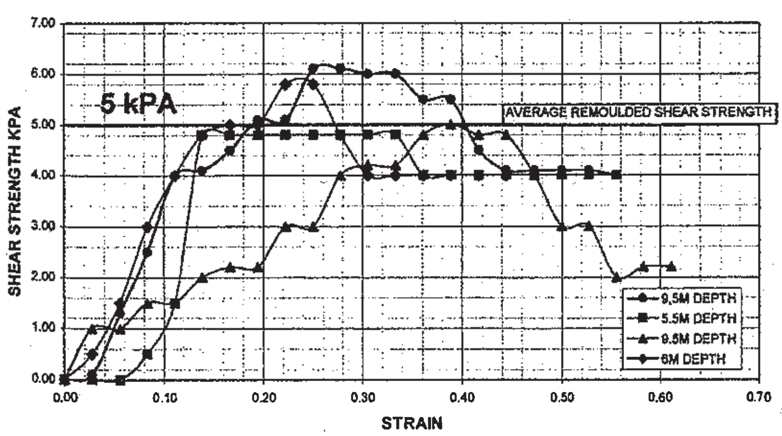

Figure 5. Remoulded shear strength.

[1] Jack-in Anchors is a patented technology by Specialist Grouting Engineers. Sdn. Bhd.

tion is residual as the installation process causes intense shearing at that region and thus taking the soil strength to its residual value. Subsequent results from pullout tests conducted a week after installation yielded higher resistance of 120 kN on average. This leads to the following unit skin resistance of 23 kPa and therefore an increase of 4 fold in the shear resistance.

Current research findings in NUS-CSGE is indicating that the predominant cause of nail set-up is due to the time dependent increase in the radial effective stress of an improved annular soil zone adjacent to the circumferential surface of the nail. This increased in radial effective stresses is due to soil disturbance caused by the displacement of soil during the installation process. This condition is very similar to set-up of piles driven in clays and hence many parallels can be drawn from this since much research work has been conducted on this subject (Randolph et al., 1979, Whittle, 1998). Plugging of the open-ended pipe was detected and this may have caused further soil disturbance as the inclusion penetrates into the soft soil mass. This points to the fact that further interfacial resistance can be mobilised if the nail inclusions were closed-ended (Whittle, 2000) since more disturbance leading to greater excess pore pressures will be incurred.

3 FINITE ELEMENT ANALYSIS

Finite element analyses were conducted using ABAQUS version 6.1 non-linear coupled finite element code.

When the nail inclusion is jack-in, assuming that the pipe nail is close-ended, it must displaced initially a volume of soil equal to the volume of the inclusion. At small penetrations, heaving occurs at the exposed ground surface. At greater penetration depths, the soil is displaced predominantly outwards in the radial direction.

This has led to the idea that a realistic approximation of the complex installation process being modelled as the expansion of a cylindrical cavity with a final radius equal to radius of the nail inclusion. Analyses of stress changes due to cavity expansion of a cylindrical and subsequent consolidation of the soil have been presented by Randolph et.al. (1979). Figure 6 briefly illustrates the boundary mesh of the problem.

The soil behaviour was modelled using an enhanced Modified Cam Clay Model where the elastic region is non-linear. Figure 7 illustrates the distribution of total pore pressure right after the installation based on cavity expansion. Around the periphery of the nail an increase of 50 kPa in excess pore-water

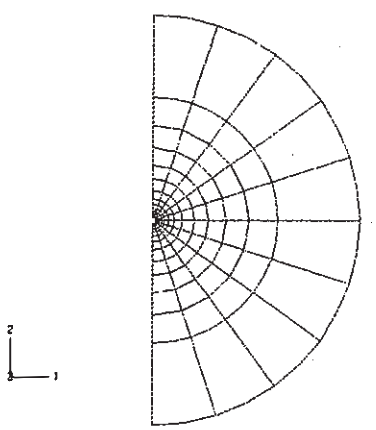

Figure 6. Finite element mesh consisting of 8-node quadrilateral reduced integration pore pressure elements.

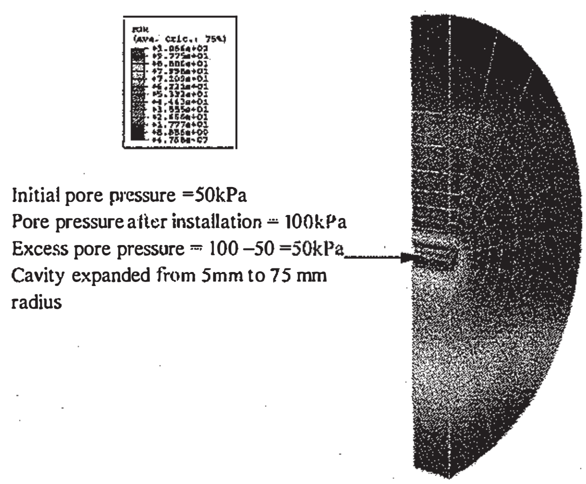

Figure 7. Plane strain finite element analysis: schematic shows the distribution of total pore pressure under 3-D view after jack-in installation by cavity expansion.

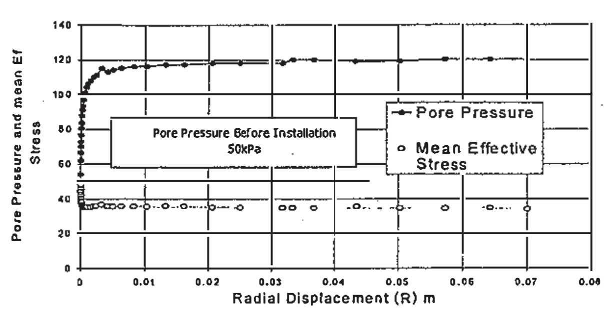

Figure 8. Build-up of pore pressure, decrement in effective mean pressure during expansion of cavity to final radius of 75mm.

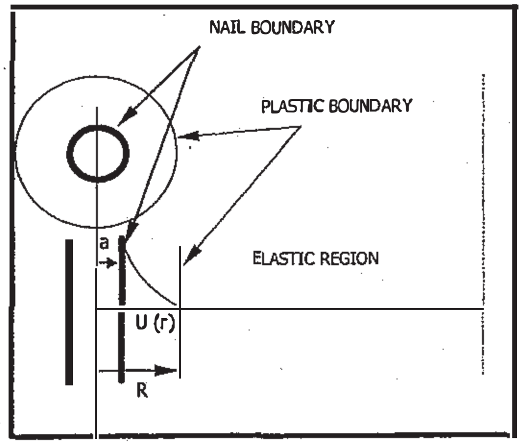

Figure 9: Radial consolidation around a cavity.

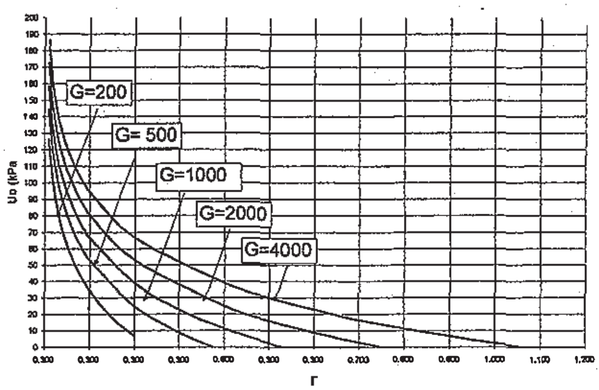

Figure 10: Distribution of excess pore pressure along the radial direction for a given expansion of 0.075m.

pressure was detected and it is reported in Figure 8. With subsequent reconsolidation (equalisation), excess pore pressure will be dissipated and this will give rise to the increased in the mean effective pressure around the periphery of the nail, hence the increased in pullout capacity. The increased in the mean effective pressure in this case corresponds roughly to 50 kPa and referring to Figure 4 again the increased in shear strength based on a normalised shear strength to mean effective pressure ratio of 0.15 will be 7.5kPa. The mean effective pressure used in the normalisation of the shear strength was calculated based on the coefficient of earth pressure at rest of unity (ko =1). Therefore if the coefficient of earth pressure was assumed to be 0.5, a larger value of Su/P' will be produced and with a unit increased in mean effective pressure (p') due to re-equalisation the theoretical increased in shear strength will be greater.

To predict the change of shaft capacity with time, Randolph and Wroth (1979) developed an analytical equation for radial consolidation of soil around a cylindrical cavity. The initial pore pressures are assumed to be those predicted by using a total stress cavity expansion analysis with the Tresca yield criterion (Yu, 2000). Simplistically, the initial excess pore pressure distribution may be obtained from the change in mean total stress. Adopting Tresca's yield criterion, the initial excess pore pressure in the plastic region can be shown to be:

$$U_0 = 2S_u \ln (R/r) \text{ for } r \leq R \quad (1)$$

Where the radius of the plastic zone is given by

$$R = (G/S_u)^{0.5} a \quad (2)$$

Beyond the plastic boundary, the initial excess pore pressures are zero (Figure 9). The above analytical equation is plotted into its graphical representation (Figure 10) for a given cavity expansion of 75mm with various values of shear modulus (G). For this case study, with a soil shear modulus of 500kPa, the estimated excess pore pressure after installation will be 60kPa. Re-equalisation will cause an increase in the mean effective pressure by an amount equivalent to the magnitude of excess pore pressure being dissipated.

Judging from field results obtained from in-situ vane tests, clay sensitivity (St) values ranges from slightly to medium sensitivity. It is speculated that thixotropy (Mitchell, 1960) may be a significant mechanism that may caused further increased in nail pull-out capacity. However further investigation will be required to assess the aforementioned hypotheses.

4 CONCLUSION

It has been observed that soil disturbance and compaction due to the jack-in installation method, soil nail set-up was the main mechanism which causes the increased in interfacial shear strength. This mechanism is a contrast to the conventional replacement method, whereby due to the soft soil conditions and the installation technique the increased in pullout capacity was not due to restrained dilatancy but the reequalisation of stresses. Research is still underway in CSGE-NUS to assess the behaviour of nail inclusions in soft soils.

5 ACKNOWLEDGEMENTS

The authors would like to thank SGE Sdn. Bhd. For the provision of field data and support. Heartfelt thanks to Ir. Dr. Gue See Sew and the staff of G&P Geotechnical Perunding Sdn. Bhd. for their help.

REFERENCES

Cheang, W.L., Tan, S.A., Yong, K.Y., Gue, S.S., AW, H.C., Yu, H.T. & Liew, Y.L. 2000, Jacked-in pipe reinforcement of a deep excavation in soft soil, Field measurements in geomechanics, 311-318, Balkema.

Hibbit , Karlson & Sorenson, Inc. , Abaqus Version 6.1 2000
Liew, S.S, Tan, Y.C. & Chen, C.S. 2000 Design, Installation and Performance of Jack-in Pipe Anchorage System for Temporary Retaining Structures, International Conference on Geotechnical and Geological Engineering. GeoEng 2000, Balkema.
Mitchell, J.K. 1960, Fundamental aspects of thixotropy in soils, Journal of Soil Mechanics and Foundations Division, ASCE, Vol.86, No.SM3, 1952.
Randolph, M.F., Carter, J.P. & Wroth, C.P.1979, Driven Piles in Clay-The Effects of Installation and Subsequent Consolidation, Geotechnique 29, No.4, 361-393.
Tan, S.A., Luo, S.Q. & Yong, K.Y. 1998, A Pullout tests of Soil Nail In Singapore Marine Clay, Second International Conference on Ground Improvement Techniques, 499-504.
Tan, S.A., Luo, S.Q. & Yong, K.Y. 1999, Analysis of Soil Nail Lateral Interaction For the Design, Journal of The Institution of Structural Engineers Singapore, Vol. No.2, 43-50.
Whittle, A.J. ,2000, Personal Communication
Whittle, A.J., Sutabutr, T., 1998, Prediction Of Pile Set-up in Clay, Transportation Research Record 1663, paper no 99-1552, 33-40.
Yu, H.S., 2000, Cavity Expansion Methods in Geomechanics, Kluwer Academic Publishers, 181-185.