Jacked-in Pipe Reinforcement of a Deep Excavation in Soft Soil

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ABSTRACT: Soil nailing is an in-situ ground improvement method which has gained increasing acceptance in this region, but is not generally recommended for clayey and organic soils. This restriction is empirically based, and little information exists on the performance of soil nails when the method is applied in these soil conditions. To address this gap, a deep excavation for the construction of a 3/12 storey deep basement carried out using a novel technique, which combines Contiguous Bored Piles and Jack-in pipe reinforcements, was instrumented to monitor its performance. This paper will highlight briefly the instrumentation program, which was set up mainly as a safety control and to monitor the interaction of this retaining system with the surrounding soft soil. In addition, numerical analyses were conducted to study the soil-structure interaction of this new construction technique. Data from the field monitoring and FEM analyses will be presented with regard to the effectiveness this system particularly the jacked-in pipes in supporting the deep excavation. It follows from this comparison that the field instrumentation and numerical analyses have proved to be valuable tools in assessing the deformations to be expected at critical stages of the excavation. The project shows that jacked-in pipe in soft clayey soils is possible, at least for short term and can be effectively used as temporary support in deep excavation.

1.0 INTRODUCTION

Deep basement construction is becoming increasingly expensive, nullifying the justification for overconservative designs. One of the ways in which construction cost can be reduced is by employing fast and cost-effective deep basement construction techniques. This paper will highlight the use of Jacked-in Pipe Reinforcement in support of Contiguous Bored Pile walls.

The field instrumentation has proven to be a valuable tool in assessing the validity of the initial design assumptions The Observational method (Peck, 1969) was practised whereby field results obtained from the adequately instrumented soil nailed retaining system were used in the back analysis of design parameters. The back calculated parameters were implemented in the Finite Element Analyses to predict deformations in the subsequent construction phases.

Soil nailing is an in-situ soil reinforcement technique, which in the last three decades has been successfully used in France, United Kingdom, United States and Southeast Asia. The origins of soil nailing partly stems from the Reinforced Earth techniques, rock bolting and multi-anchorages systems (Recommendations Clouterre 1993). Soil nailing has been primarily used for temporary retaining structures for basement excavation and permanent cut-slope stabilisation. Jacked-in pipe retaining system, which is similar to soil nailed system is not common. This technique has gained momentum in Malaysia mainly for the ease and speed of installation and it is also very cost effective.

However, with the advent of numerous research programs (Schlosser, 1986; Elias and Juran, 1990), increase in the state-of-understanding and experience, both abroad (Schlosser, 1982;Bruce and Jewell, 1986, Bruce and Jewell 1987, Juran et al., 1990;) and local (Tan, et al., 1998; Luo et al., 1998; Tan et al., 1999) will promote the use of this technique, both as a temporary and permanent structure.

2.0 DESCRIPTION OF PROJECT

The condominium project which is located at UEP Subang Jaya of Malaysia consists of three condominium towers of 33 storey and a single 20 storey office tower. Due to the huge demand for parking space, an approximately three storey deep vehicular parking basement will be required. The deep excavation, through a filled layer of very loose silty sand and soft peaty clay varies from 11m to 13m. The presence of very soft soil condition and the fast track requirement of the project, Contiguous Bored Pile (CBP) walls supported by Jack-in Pipes in six to seven rows were utilised to stabilise and control the lateral displacement and surface settlement. The supported face is approximately 6900 m^2.

Photo 1: The Retaining System; Contiguous Bored Piled Walls (CBP) and Jack-in Soil Nails

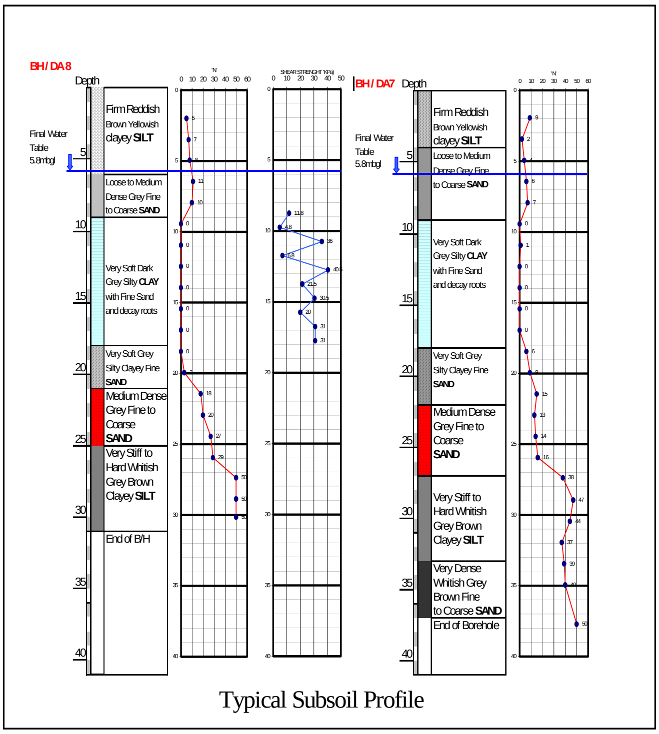

Fig. 1:Typical Subsoil Profile

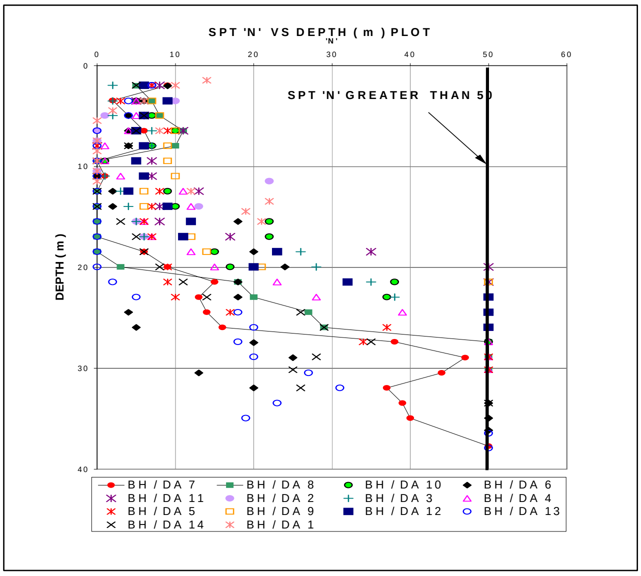

Fig. 2: SPT 'N' Values: Scatter Plot

3.0 GEOLOGICAL INFORMATION

The general subsurface soil profile of the site, shown in Fig.1 consists in the order of succession a firm clayey SILT, a loose to medium dense SAND followed by firm to hard clayey SILT. The soils are inter-layered by thick deposits of very soft dark peaty CLAY.

The plot of SPT'N' values, illustrated in Fig.2, shows significant scattering which is commonly found in tropical residual soils in the area. However the trend of the scatter plot shows that the SPT 'N' values increases with depth. For the underlain soft clayey material, the registered SPT 'N' values were zero and Vane Shear strength varies from 5 kPa to 20 kPa. For analysis purposes the subsoil was simplified into representative layers, namely Granular material and Cohesive material.

4.0 THE JACKED-IN PIPES AND CONTIGUOUS BORED PILE SYSTEM

Jacked-in Pipes Reinforcement

Mild steel pipes which functions as soil nails are installed by hydraulic jacking. This method has proven to be an efficient and effective technique for excavation support, where conventional soil nails and ground anchors have little success in such difficult soft soil conditions. Such conditions are sandy collapsible soil, high water table and in very soft clayey soils where there is a lack of short-term pullout resistance.

In view of the close proximity of commercial buildings to the deep excavation, a very stiff retaining system is required to ensure minimal ground movements the retained side of the excavation. Contiguous Bored Piles which acts as an earth retaining wall during the excavation works were installed along the perimeter of the excavation and supported by Jack-in pipes.

In the initial design of the retaining system, conventional ground anchors were proposed, but the jacked-in pipes were accepted as an alternative to ground anchors due to speed and cost-effectiveness of the system. Relatively, larger movements are required to mobilised the tensile and passive resistance of the jacked-in pipes when compared to ground anchors. However it was anticipated that the ground settlement at the retained side and maximum lateral displacement of the wall using this system would still be within the required tolerance after engineering assessment.

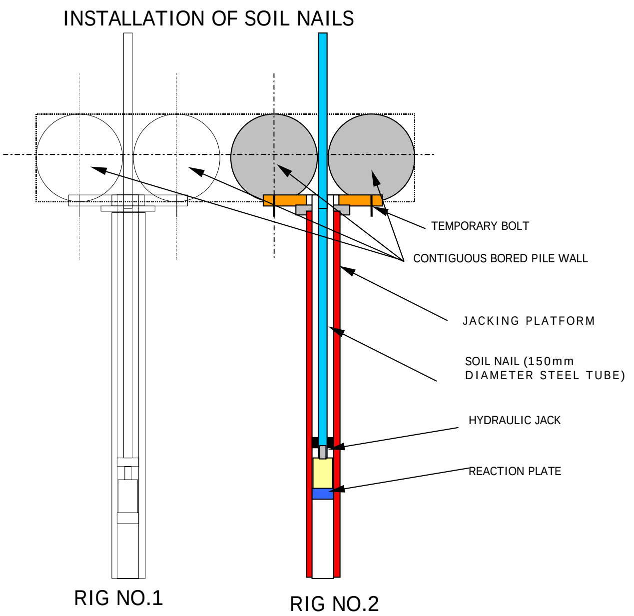

Fig. 3: Schematic of Jack-in Soil Nails

5.0 SEQUENCE OF CONSTRUCTION

The layout of Contiguous Bored Pile retaining wall as detailed in Fig. 3 forms the basement wall of the substructure. The retaining wall system consists of closely spaced 1000mm diameter bored piles near the commercial buildings and 800mm diameter for area away from the commercial buildings. To facilitate the Top-Down excavation of the deep basement, roller pipes of 150mm diameter were jacked in sub-horizontally after each excavation stage. The phases of the basement construction are described as follows (currently during the writing of this paper, construction has only reached the 4th level of excavation):

Stage 0	Installation of Contiguous Bored Pile Wall
Stage 1	Excavation 1: Excavation to 2.7m below ground level
Stage 2	Jacked-in pipe: Level 1 at 1.7m below ground level.
Stage 3	Excavation 2. Excavation to 4.5m below ground level.
Stage 4	Jacked-in pipe: Level 2 at 3.5m below ground level.
Stage 5	Excavation 3: Excavation to 6m below ground level.
Stage 6	Jacked-in pipe: Level 3 at 5m below ground level
Stage 7	Excavation 4: Excavation to 7.5m below ground level
Stage 8	Jacked-in pipe: Level 4 at 6.5m below ground level

6.0 GEOTECHNICAL INSTRUMENTATION

In view of this relatively new excavation support technique, in-situ soft soil conditions and the close proximity of the commercial buildings to the deep excavation, a performance monitoring program was provided. Firstly, as a safety control. Second, to refine the numerical analysis using field measurements obtained at the early stages of construction and third, to provide an insight into the possible working mechanisms of the system.

The geotechnical instrumentation program consists of 18 vertical inclinometer tubes located strategically along the perimeter of the Contiguous Bored Pile wall and 30 optical survey makers (surface settlement points) near the vicinity of the commercial buildings. This instrumentation would provide sufficient readings to monitor the performance of the excavation system.

The locations of these instruments are detailed in Fig. 4 for the inclinometers and Fig. 5 for the optical survey points. Vertical inclinometer readings were taken once weekly and the surface settlement readings were taken once every two weeks. However when critical stages were involved, the frequency of the readings was increased both as a safety control and to provide sufficient field data for numerical modelling.

Fig. 6 illustrates the trend of horizontal displacement of the wall as measured through inclinometers installed at the site.

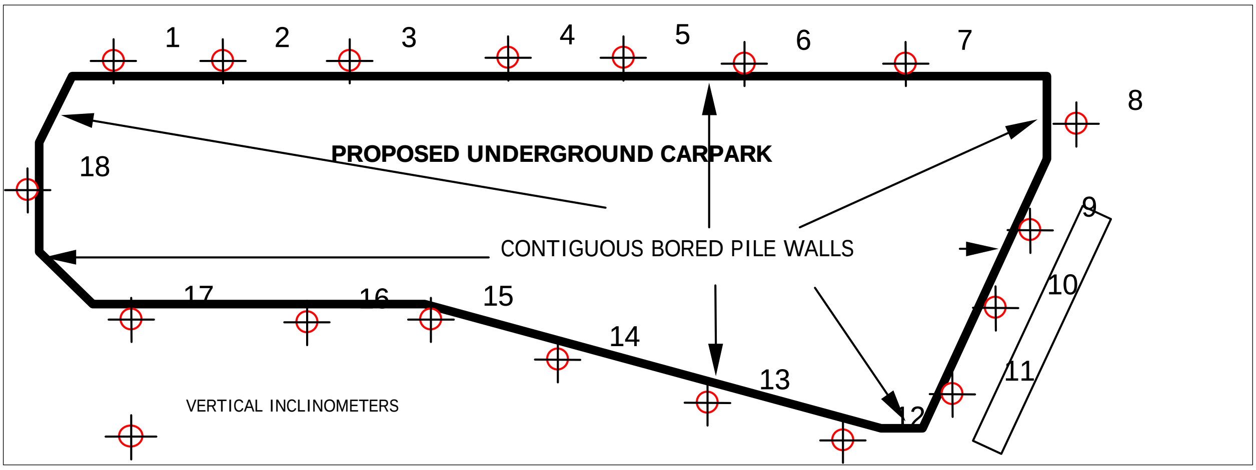

Fig. 4: Layout of Vertical Inclinometers

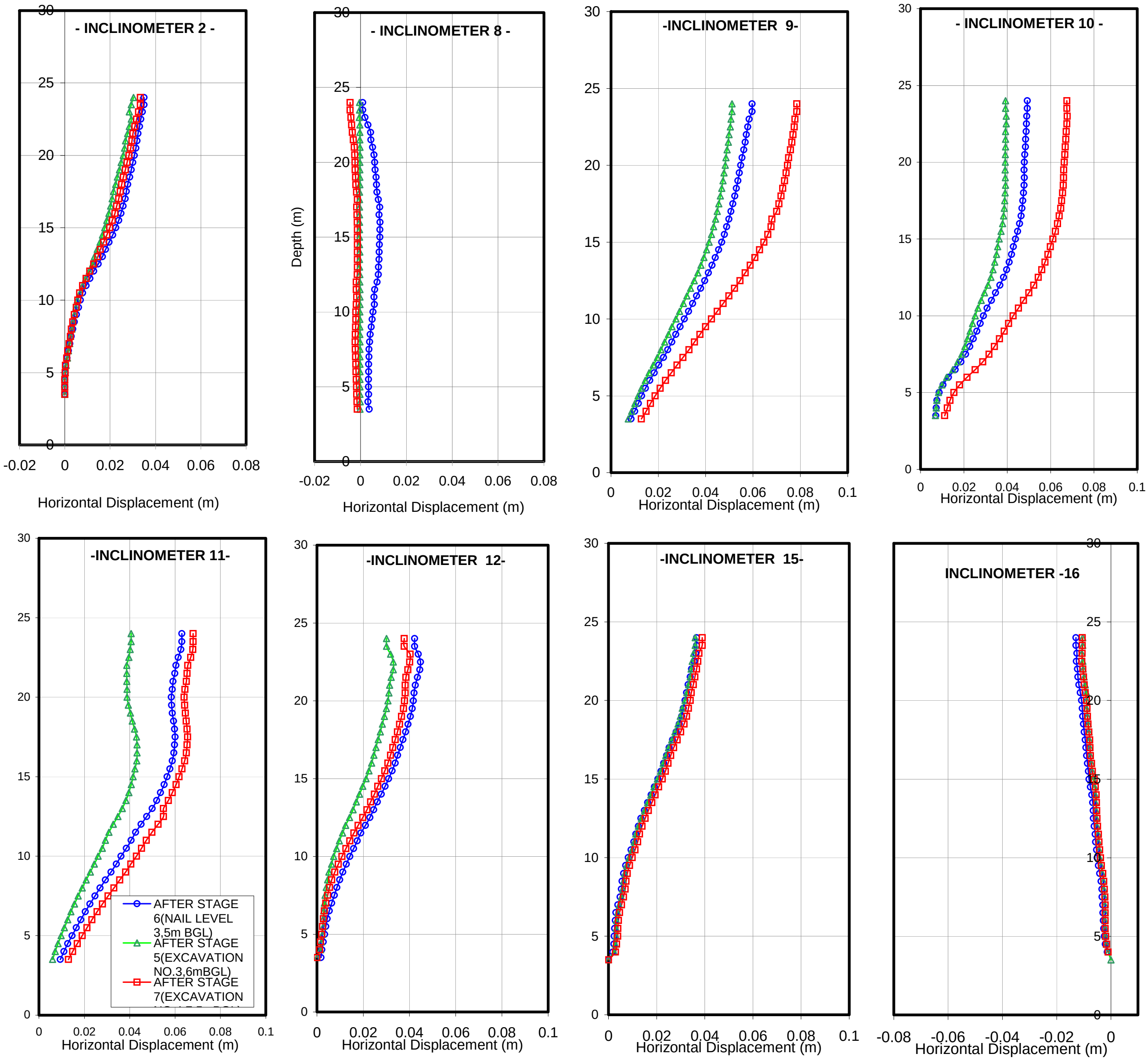

Fig. 6: Measured Horizontal Displacements of Contiguous Bored Pile Walls supported by Jacked-in Soil Nails

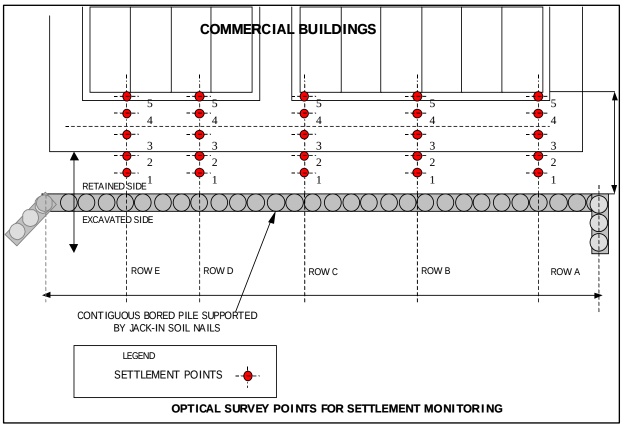

Fig. 5: Layout of Settlement Markers

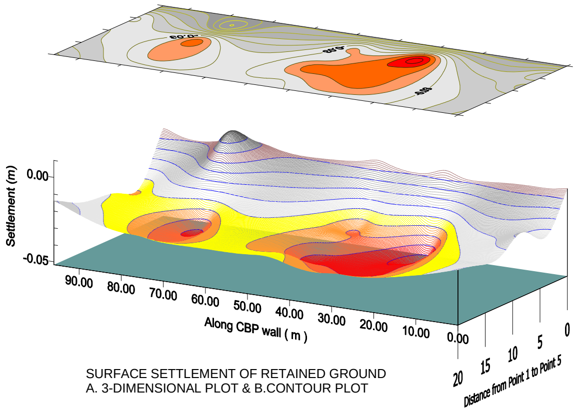

Fig. 7: Variation of vertical settlement from field performance

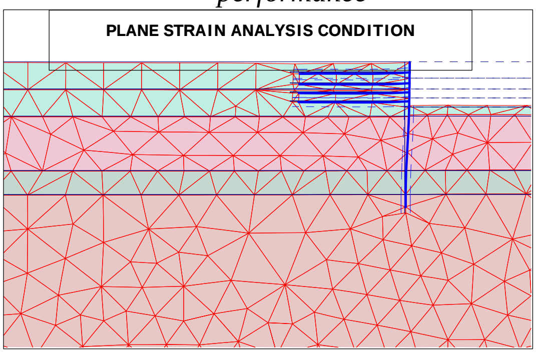

Fig. 8: Plane Strain Analysis (Plaxis V 7.11)

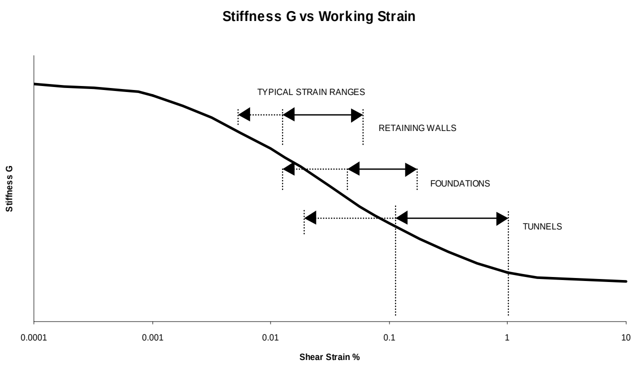

Fig. 9: Typical Shear Modulus and working shear strains for different geostructures (after Mair, 1993)

7.0 NUMERICAL MODELLING

Design methods recommended at the present time is still based on classical limit equilibrium methods, which only evaluate the stability of the structure. However when constructing deep excavations in highly urbanise areas, the Serviceability Limit State of a retaining system will be the governing factor.

The Contiguous Bored Pile wall supported by internally stabilising jacked-in pipes is essentially a 3-D numerical problem. This can be seen from the results of the instrumentation as indicated in Fig. 6 where deformations are restrained at the corners due to edge effect (inclinometer 8) and the maximum occurring approximately at the centre of the wall (Inclinometer 9 & 10).

Due to the complex soil-pipe, soil-wall and pipe-wall interaction, a global soil arch will be formed (Schlosser et al., 1997;Benhamida et al, 1997). In addition to this, local arching will develop between the pipes, and therefore creating concentration of stresses. With good engineering judgement and practise a 3-D problem can still be effectively modelled as a 2-D plane strain problem. The numerical analyses were performed using "Plaxis" (Brinkgreve and Vermeer, 1998) a Finite Element Method computer program under plain strain condition (Fig. 8). The Contiguous Bored Pile wall and hollow steel pipes were modelled using a linear elastic model and its material properties converted to the equivalent 2D parameters through area ratio factors (Al-Hussaini & Johnson, 1978). The model pipes were elastic and pinned to the Contiguous Bored Pile wall. An elastic -perfectly plastic model was used to model the behaviour of the soil-pipe interface. The model, which uses the Coulomb criteria, distinguishes between the elastic behaviour, where small displacements can occur within the interface, and plastic interface behaviour (slip).

It is well established that the subsoil stiffness is not a constant value and is dependent on strain levels. Mair (1993) reported the changes of soil stiffness with different working strain levels for various geostructural systems as detailed in Fig. 9. The typical working range of retaining walls is in the order of 0.01-0.1%.It highlighted the inadequacy of conventional laboratory tests in evaluating the in-situ soil stiffness and the soil

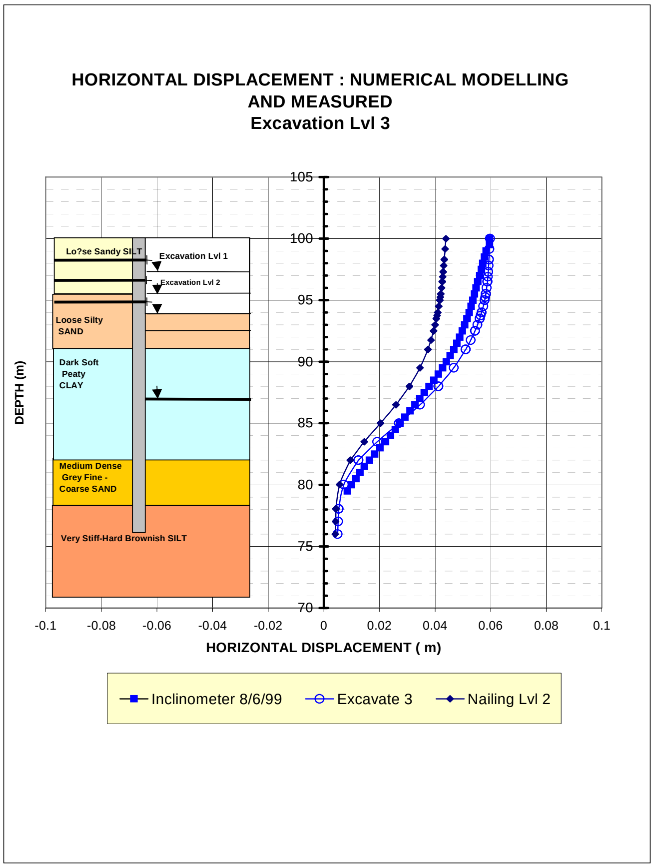

Fig. 10 a

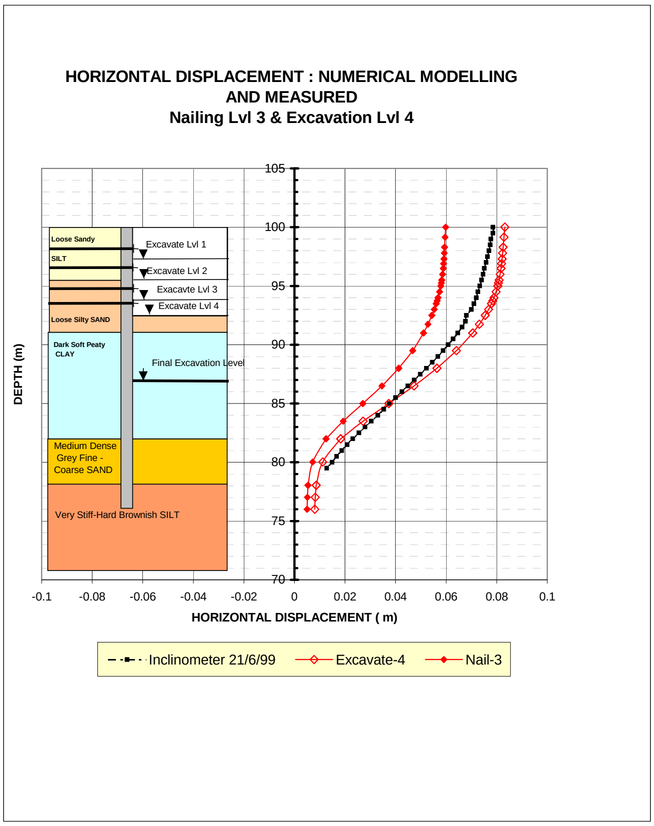

Fig. 10b

Fig. 10: Measured Field Performance and Finite Element Analysis for; a) Nail Level 2 & Excavation Level 3, b) Nail Level 3 & Excavation Level 4

stiffness obtained from these tests is several magnitudes lower than the in-situ soil stiffness.

The undrained soil modulus for the Soft Peaty Clays were assumed to be Eu = 700 Su (Gue, 1997(b); Gue, 1998) for all stages of excavation. The soil modulus for the fill soils (Sands) were assumed to be E' = 3500N based on Stroud and Butler (1975), where the N Standard Penetration Test Value. For the Clayey Silt, Eu = 700 Su and Su = 5.5N was adopted. In addition to this, the soil is undergoing unloading and therefore the in-situ soil stiffness will be a few magnitudes higher compared to loading condition.

Fig. 10a and 10b presents comparisons between the FEM analysis and field performance for 6m and 7.5m deep excavation respectively. The results show that the Young's modulus for the various soil layers were very close to the assumed values and were used in the subsequent deformation predictions and parametric studies.

The predicted deflections of the wall at the 3rd and 4th stage of excavation show approximately a very similar deflection profile to the measured field profile. The wall is behaving in a fashion very similar to a cantilevered wall and the pipes seemed to be restraining the deflection at the upper section of the wall. Generally, most of the measured field performance displays such a restraint cantilever profile as shown in Fig. 6. However, the prediction for all stages particularly the 4th stage was slightly over-predicted. There are few possibilities that may have influenced the predicted deformation profile, notably small strain behaviour, where at very small strains the soil exhibits a much higher soil modulus (Jardine et al 1985; Burland, 1989) and therefore the soil tends to deform less.

An analysis was performed without the nail inclusions, where the retaining wall was modelled as a cantilever wall. Fig. 11 compares the deflection profile between the cantilevered wall and 'improved' wall at 7.5m deep of excavation. It shows a distinct restraint offered by the jacked-in pipe inclusions. The influences of pipe bending on the reinforcement mechanism and has been a subject of great debating (Bridle & Barr, 1990; Jewell & Pedley; 1990; Schlosser, 1991; Jewell & Pedley, 1991). Fig. 12 compares the deflection profile of retaining wall where the jacked-in pipes were modelled using;

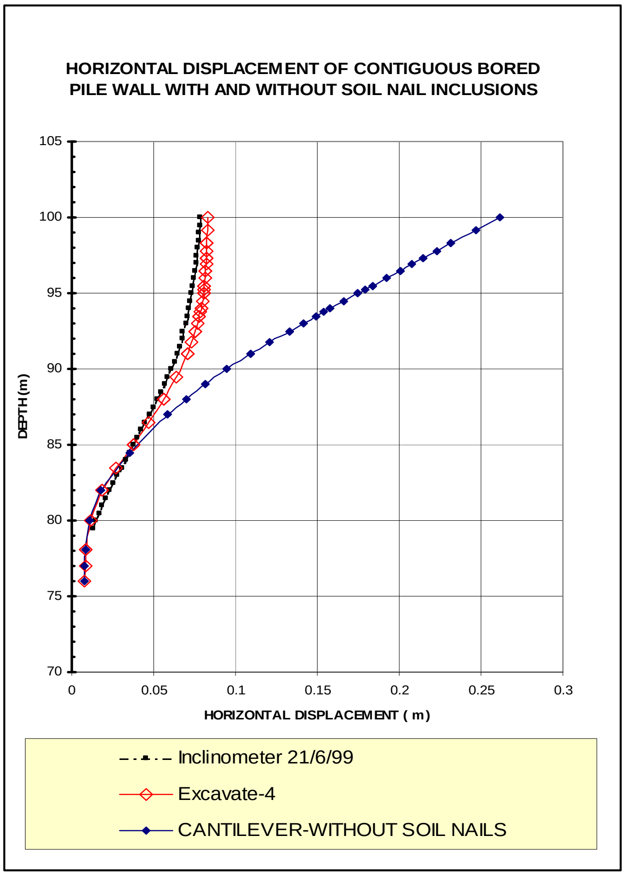

Fig. 11:Parametric: Contiguous Bored Pile wall with and without Soil Nail Inclusions

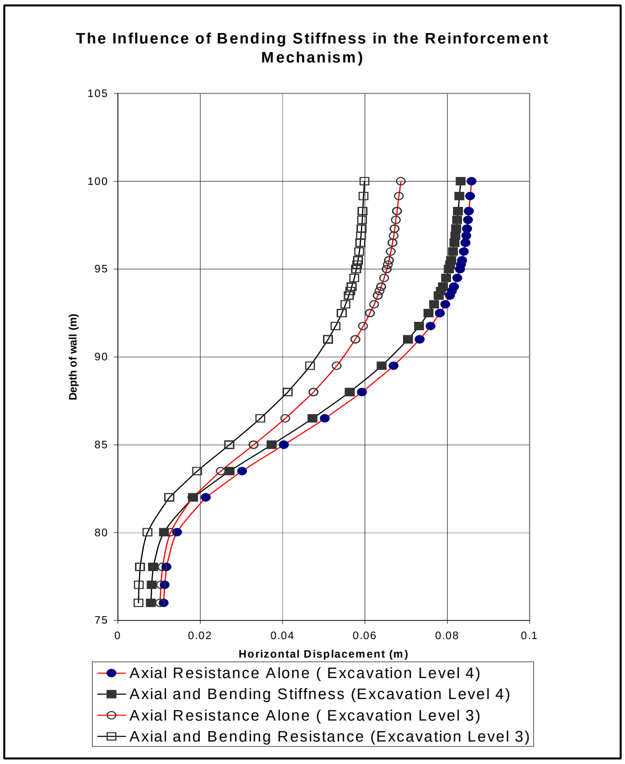

Fig. 12: Parametric Analysis, Influence of Bending Stiffness on the Reinforcement Mechanism

a) beam elements with an axial stiffness and a flexural rigidity, and b) flexible elastic elements (geotextile element in Plaxis) with only the axial stiffness. Fig. 12 shows that bending stiffness has an influence in the reinforcement mechanism, where jacked-in pipes modelled using the beam elements show a smaller displacement compared to the geotextile elements in all of the numerical stages. A large-scale experimentation in soft clays conducted by Oral et al (1998) has indicated that due to lack of nail-pullout, nail bending played a major role in the reinforcement mechanism. A similar behaviour was observed in this project where the initial nail pullout was extremely low and increases through time. This reinforced the idea that additional analyses of different failure mechanisms should be addressed in different soil types particularly in soft soils.

The numerical surface settlement was found to be less compared to the measured field surface settlement. This may be due to the fact that the jacked-in pipes were modelled as beam elements which are essentially plate elements 'smeared' across a unit width in the plain strain analysis. This will restrain the soil from 'flowing' around the nails. However this assumptions is valid if the horizontal spacing of the pipes is closely spaced. The other possible reason could be the increase in effective overburden pressure when water table has dropped after excavation.

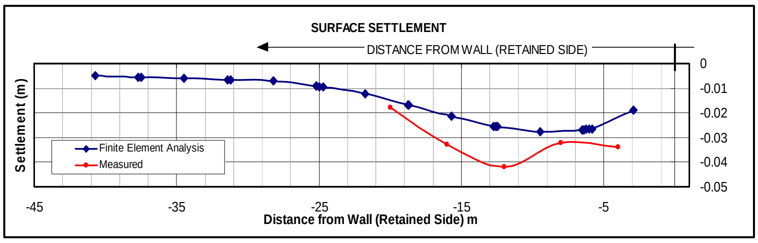

Fig. 13: Surface Settlement: Measured Field Performance and Prediction from Finite Element Analysis

8.0 CONCLUSION

Instrumentation has an important role in geotechnical engineering, specifically when the state-of-practice of a particular geosystem is ahead of the state-of-art.

The performance monitoring program implemented in this project was not solely used as a safety control, but as well as to gain an insight into the possible working mechanisms. Back calculated design parameters were used in the prediction of deformations in the subsequent construction phases and this has greatly reduced the risks, which comes from the implementation of the new retaining system. This project shows that jacked-in pipes in soft clayey soils is possible at least for short term and can be effectively used as a temporary support in deep excavation.

9.0 REFERENCE

1. **Benhamida, B., Schlosser, F., Unterreiner, P., (1997),** Finite Element Modelling of Soil Nailed Wall: Earth Pressures and Arching Effects, *Numerical Models in Geomechanics*, Balkema, pp.245-250.
2. **Brinkgreve, R.B.J., Vermeer, P.A., (1998),** PLAXIS-Finite Element Code for Soil and Rock Analyses-Version 7.A.A.Balkema.
3. **Bruce, D.A, Jewell, R.A, (1986)** Soil Nailing Application and Practice-Part 1,*Ground Engineering*, Vol.19, No.8, pp.10-15.
4. **Bruce, D.A, Jewell, R.A, (1987)** Soil Nailing Application and Practice-Part 2, Ground Engineering, Vol. 20, pp.21-33.
5. **Bridle, RJ, (1989)** Soil Nailing-Analysis and Design, *Ground Engineering*, Sep 1989,pp.52-56.
6. **Bridle, R.J., Barr, BIG, (1990)** Soil Nailing, Ground Engineering, July/August, pp.30-33.
7. **Burland, J.B., (1989)** Small is Beautiful-The Stiffness of Soil at Small Strains, *Ninth Laurits Bjerrum Memorial Lecture*, Canadian Geotechnical Journal, Vol.26, pp.499-516.
8. **Elias, V., Juran, I., (1991)** Soil Nailing for Stabilisation of Highway Slopes and Excavations" *United States Federal Highway Administration, Publication No. FHWA-RD-89-193*, June.
9. **French National Research Project CLOUTERRE (1993)**, *Recommendations Clouterre 1991-Soil Nailing Recommendations, Presses de l'Ecole Nationale des Ponts et Claussees.*
10. **Gue, S.S, (1997a),** Interpretation of Laboratory and Field Test Results for Designs Paper 2,Short Corse on Site Investigation Practice, *The Institution of Engineers, Malaysia, Kuala Lumpur.*
11. **Gue,S.S, (1998),**Selection of geotechnical Parameters for design,*Short Course on geotechnical Engineering, The Institution of Engineers,Malaysia,Kuala Lumpur*.
12. **Jardine, R.J, Symes, M.J., Burland, J.B.,** The Measurement of Soil Stiffness in the Triaxial Apparatus, *Geotechnique*, 34(3), pp.323-340.
13. **Jewell, R.A, Pedley, M.J, (1990)**, Soil Nailing Design: The Role of Bending Stiffness, *Ground Engineering*, March, pp.30-36.
14. **Jewell, R.A, Pedley, M.J, (1991**), Discussion to F.Schlosser, *Ground Engineering*, Nov, pp.34-39.
15. **Luo,S.Q,Tan,S.A,Yong,K.Y,(1998),** Stabilisation of Basement Excavation with Soil Nails and Ground Anchors, *2nd International Conference on Ground Improvement techniques*: 8-9 October ,Singapore pp.327 –336
16. **Mair,R.J,(1993**) Developments in Geotechnical Engineering Research: Application to Tunnels and Deep Excavations, *Unwin Memorial Lecture 1992,Proc.of.the.Inst.of Civil Engineers-Civil Engineering*.pp.27-41.
17. **Oral,T,Sheahan,T.C.,(1998)**The Use of Soil Nails in Soft Clays, Design and Construction of Earth Retaining Systems,Proc. Of Sessions of geo-Congress 1998,pp. 26 –40.
18. **Peck,R.B,(1969),**Advantages and Limitations of the Observational Method in Applied Soil Mechanics,*Geotechnique,*Vol.19,No.2pp.171-187
19. **Schlosser, F., (1982),** Behaviour and Design of Soil Nailing, *Proc. Intl. Symp, Asian Institute of Technology*, Bangkok, 29Nov-3 Dec, 1982,pp399-419.
20. **Schlosser,F,(1991),** The Multi-criteria Theory in Soil Nailing,*Ground Engineering,*Nov.,pp.30-33.
21. **Tan, S.A, Luo, S.Q, Yong, K.Y, (1998),**A Pull-out Test of Soil Nail in Singapore Marine Clay,*2nd International Conference on Ground Improvement techniques*: 8-9 October ,Singapore pp.499-504.
22. **Tan, S.A, Luo, S.Q, Yong, K.Y, (1999)** Analysis of Soil Lateral Interaction for Design, *Journal of the Institution of Engineers Singapore*,vol. 39,No.2, pp.43-50.
23. **Unterreiner,P., Benhamida,B., Schlosser, F., (1997),**Finite Element Modelling of the Construction of A Full-Scale Experimental Soil-Nailed Wall. French National Research project CLOUTERRE, *Ground Improvement*,,pp.1-8.
24. **Smith, I.M.,Su,N.,(1997)** Three Dimensional FE Analysis of A Soil Nailed wall Curved in Plan.*International Journal for Numerical and Analytical Methods in Geomechanics*,Vol.21,pp. 583-597.