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Behavior and performance of deep excavation in residual soils near sensitive structures

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ABSTRACT : This paper describes the behavior of ground and adjacent structures observed by various types of instruments during substructure construction of a 15-storey hospital extension with 3 to 4-level of basement located in close proximity to the existing old hospital ward block, road and MRT tunnels. Discussions on the characteristics of ground/structure movements and comparison between observed and predicted movement values are also presented in this paper.

1 GENERAL

Construction involved deep excavation in close proximity to sensitive structures such as MRT tunnels, roads and old buildings supported on footings requires a well understanding of the engineering characteristics of the subsoils, good engineering judgement in the selection of construction method as well as suitable instrumentation system for achieving practical/economical design, safe construction and timely completion of project. The recently completed New Tan Tock Seng Hospital involved the construction of 3 to 4-level basement in closely proximity to the existing MRT tunnels linking Novena Station and Toa Payoh Station and a 6-storey hospital ward block (Figure 1) was constructed under stringent control in view of its sensitive environment and the complicated geology.

2 PROJECT DESCRIPTION

The project site is roughly rectangular and approximately 191m by 135m (i.e. 25,785sq.m) with surface elevation varying from EL105m at north-west to EL120m at north-east. The excavation for basement construction went down to a max. depth of 16.5m below the existing grade. A combination of open cut and braced excavation method using stable cut slope and bored pile retaining walls (Table 1) was adopted in the basement construction of this project.

Table 1 Summary of Bored Pile Retaining Walls for Basement Excavation

Wall No.	Pile Sizes		Depth of Excavation (m)	Max. Movement Recorded (mm)	Types of Supports
	Diameter (mm)	Spacing (mm)			
GRW 1	800	1600	16.5	19.1 (I-8A)	Ground Anchors
GRW 2	1300	1600	16.5	17.3 (I-9) / 33.9 (I-10)	Ground Anchors
GRW 3	1000	1500	12.1	9.6 (I-12A) / 54.6 (I-11A)	Horizontal Struts
CBP 1	1100	1200	3.5	-	Cantilever
CBP 2	1100	1200	7.5	25.8 (I-3)	Cantilever / Rakers
CBP 3	800	900	16.5 / 15.3	32.8 (I-5) / 22.2 (I-6)	Ground Anchors

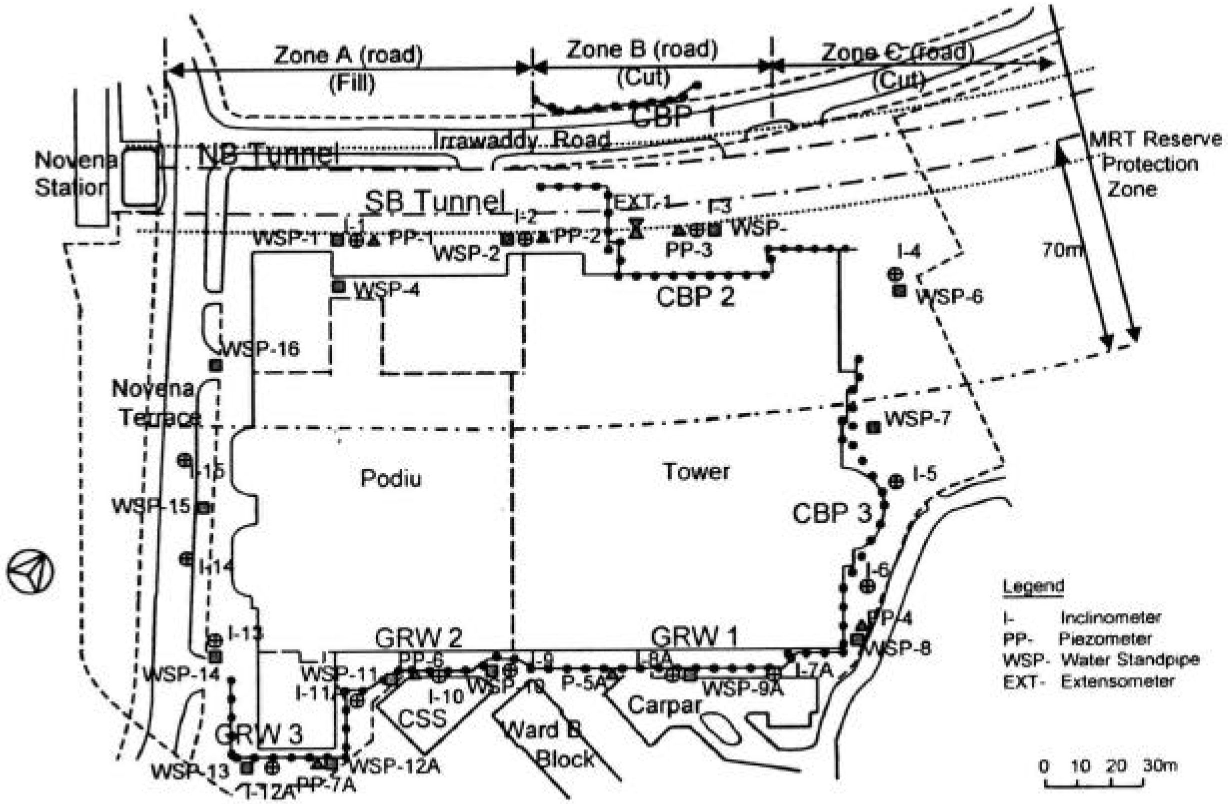

Fig. 1 Site and instruments layout plan

3 SOIL CONDITION

According to the results of site investigation (MAA 1991), the subsoil condition of the project site was found very erratic between the north-eastern and north-western parts of the site. The project site is situated in the Jurong Formation and underlain by a layer of medium dense Clayey SAND and/or stiff Sandy SILT (i.e. Layer 1, N=2 to 15) extending from ground surface to a depth zone of 15.0~28.5m in north-west and 1.5~6.0m in north-east. Immediately underneath Layer 1 is a layer of dense Silty SAND and/or hard Sandy SILT (i.e. Layer 2, N=15 to 50) which extends to a depth zone of 16.5~33.0m in north-west and 3.0~8.0m in north-east. A layer consisting of very dense Silty SAND and/or very hard Sandy SILT with weathered rock (i.e. Layer 3, N=50 to over 100) was found underneath Layer 2 and extending to a max. depth of 39.6m below the existing grade. SPT-N values over 100 were recorded in Soil Layer 3 at erratic depth zone ranging from 18.9 to 34.5m and 3.0 to 11.0m below grade in the north-western and north-eastern parts of the site, respectively (Figure 2).

Table 2 Types and Quantities of Instruments

Type of Instruments	Quantities
Inclinometer	15
Pneumatic Piezometer	10
Water Standpipe	16
Surface Settlement Point	89
Extensometer	1
Vibration Sensor	5
Automatic Tunnel Monitoring Device (TM3000V)	2
Manual Survey	-

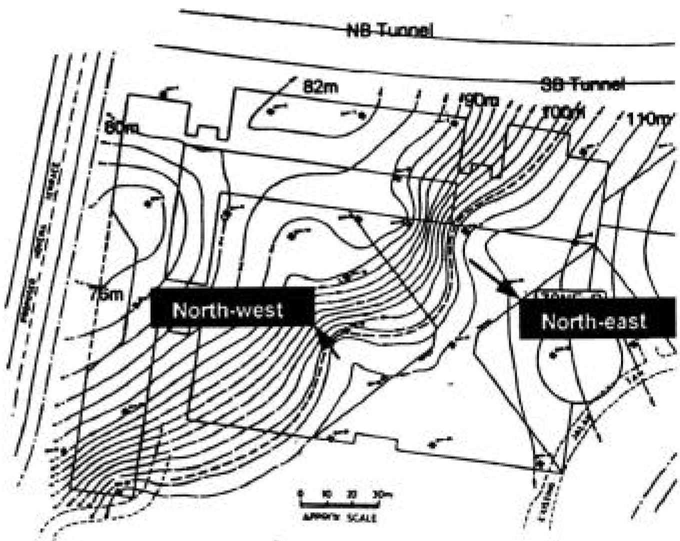

Fig. 2 Surface Contours of N>100 Soil Layer

4 INSTRUMENTATION

To comply with the requirements on tunnel protection imposed by the Authority and to ensure the safety of the adjacent structures during excavation, a comprehensive instrumentation program consisting of various types of ground and tunnel monitoring instruments (Table 2) has been implemented for construction safety control of this project.

5 WALL DEFLECTION

In order to avoid serious settlement of the surrounding ground, especially in the vicinity of the 6-storey hospital ward block, contiguous bored pile walls with adequate stiffness supported by ground anchors (Table 1) were adopted in the excavation work to minimize detrimental effect on the adjacent structures. The behavior of walls under each stage of excavation were analyzed by using the Oasys computer program "FREW" in term of effective stress method. Figures 3 & 4 show the change of lateral movement at selected depths recorded by two (2) typical Inclinometer Nos. I-5 and I-9, respectively during each stage of excavation. Sequential wall deflection profiles of these two inclinometers are shown in Figures 5 & 6. As indicated in Figures 3 & 4, the wall deflections increased rapidly with depth of cut and tended to be stabilized after the excavation was completed and adequate supports were provided. Figure 7 shows "characteristic curves" (Moh et al 1999) for wall deflections and Figure 8 shows a plot of normalized wall deflections versus depth of excavations for the present case with α value ranging from 39 to 201.

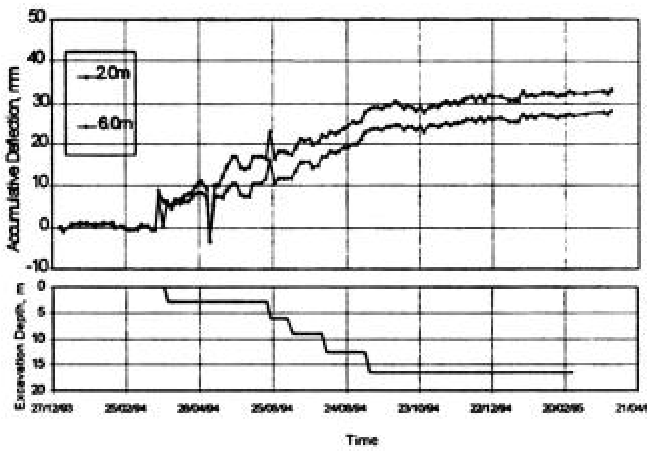

Fig. 3 Change of lateral movement recorded by I-5

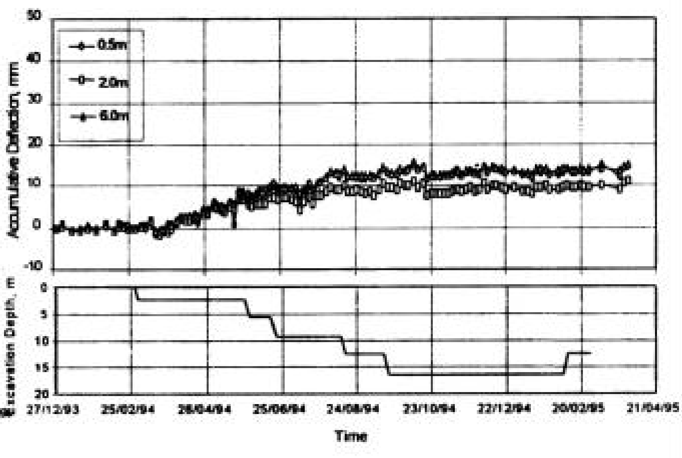

Fig. 4 Change of lateral movement recorded by I-9

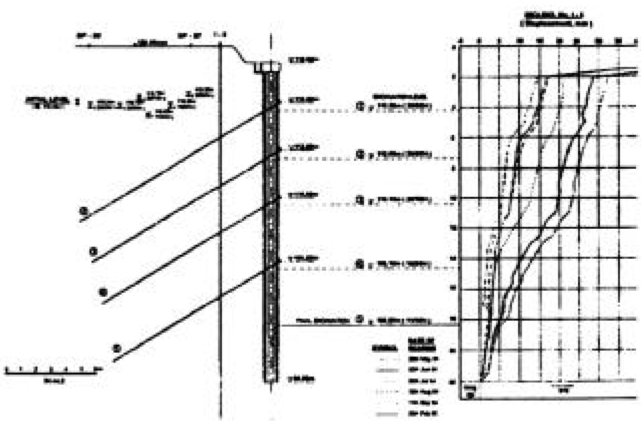

Fig. 5 Typical excavation profile at CBP 3 (I-5)

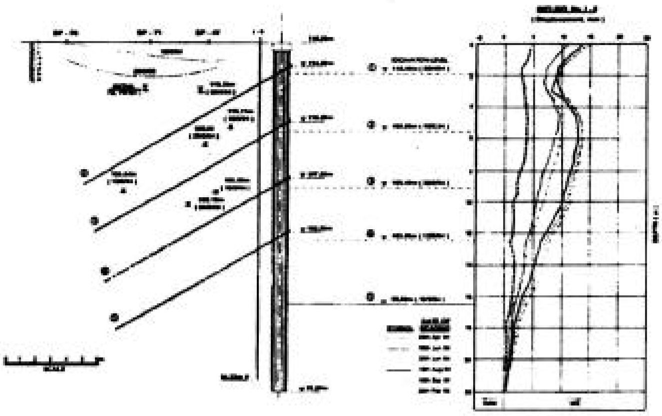

Fig. 6 Typical excavation profile at GRW 2 (I-9)

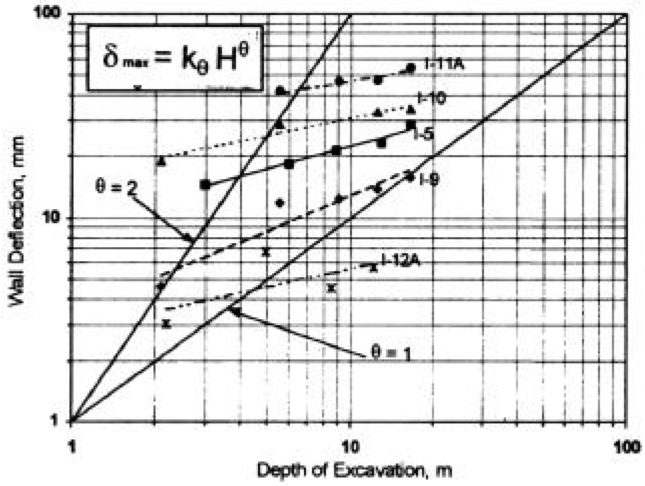

Fig. 7 Wall deflections versus excavation depth

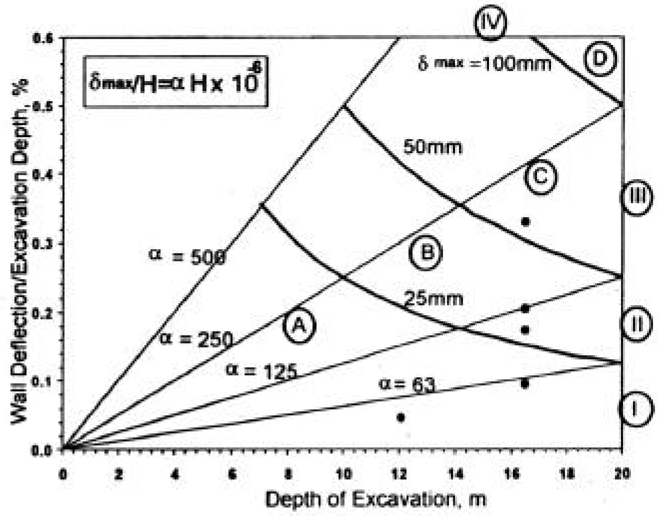

Fig.8 Wall deflections in Jurong Formation (TTSH)

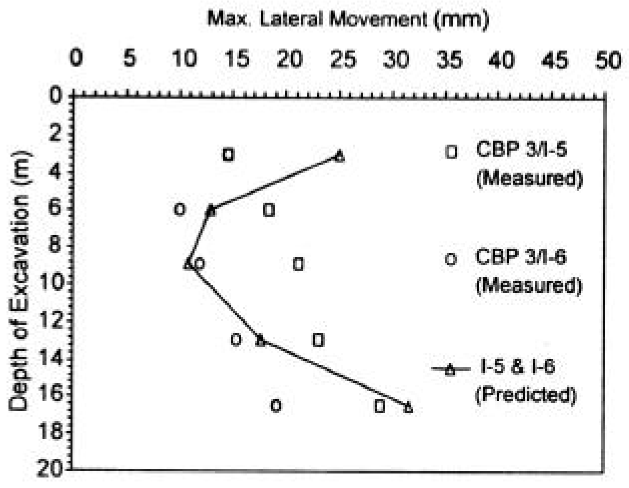

Fig.9 Comparison of measured and predicted max. lateral movement (CBP 3)

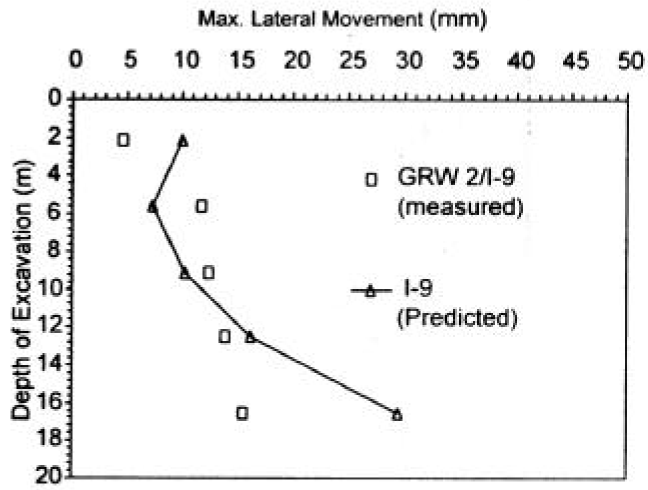

Fig.10 Comparison of measured and predicted max. lateral movement (GRW 2)

Figures 9 & 10 show the predicted (from FREW analysis) and measured max. lateral movements of two (2) bored pile walls with respect to each stage of excavation. The measured deflection values appear to be reasonably close to the predicated deflection values.

6 GROUND SETTLEMENT

Ground settlement behind the retaining walls were monitored by surface settlement points during each stage of excavation. Noticeable ground settlement (max. 26mm) was found within a distance of 2 x "H" (H is the excavation depth) from the excavation boundary and the magnitudes of maximum settlement were found to be about 39 to 131% (i.e. Ave. 87±40%) of the measured lateral wall movements for the present case.

7 BUILDING MOVEMENT

The monitoring results of building settlement points installed on the 6-storey Ward B Block and the single storey CSSD building showed maximum settlement values of 9 and 10mm, respectively during the excavation and substructure construction period. This magnitude of building settlement is about 52 to 58% of the maximum lateral movement recorded by the adjacent Inclinometer No. I-9. No significant tilt was recorded by the tiltplates installed on Ward B Block during the excavation period.

8 GROUNDWATER LEVELS

The monitoring results (Figures 11 & 12) of water standpipes indicate that the groundwater levels declined steadily during excavation and stabilized after earthwork activity was completed. Obvious drop in groundwater level was observed by Water Standpipe Nos. WSP-10 & WSP-11 installed at GRW 2 where the largest ground movements were observed. This obvious drop is believed to be localized and could be attributed to the existence of fractured decomposed rock at this location.

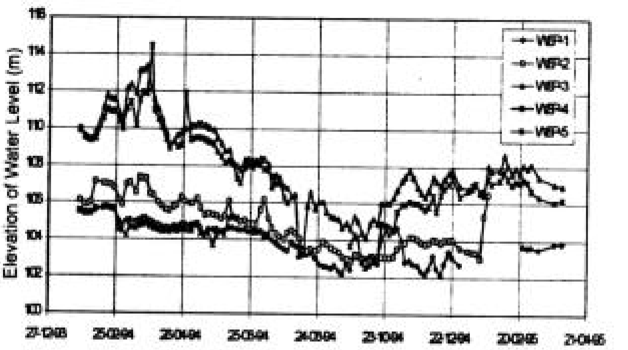

Fig. 11 Groundwater level observation (CBP 2)

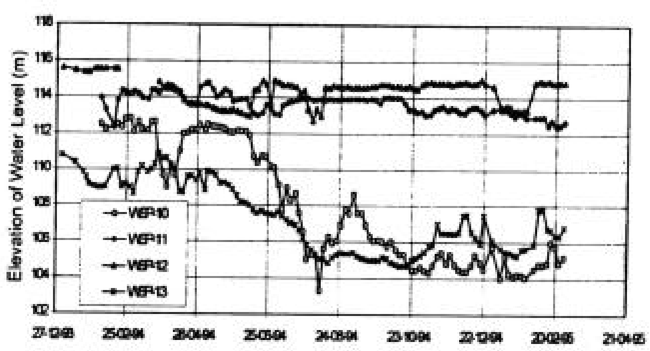

Fig. 12 Groundwater level observation (GRW 2/3)

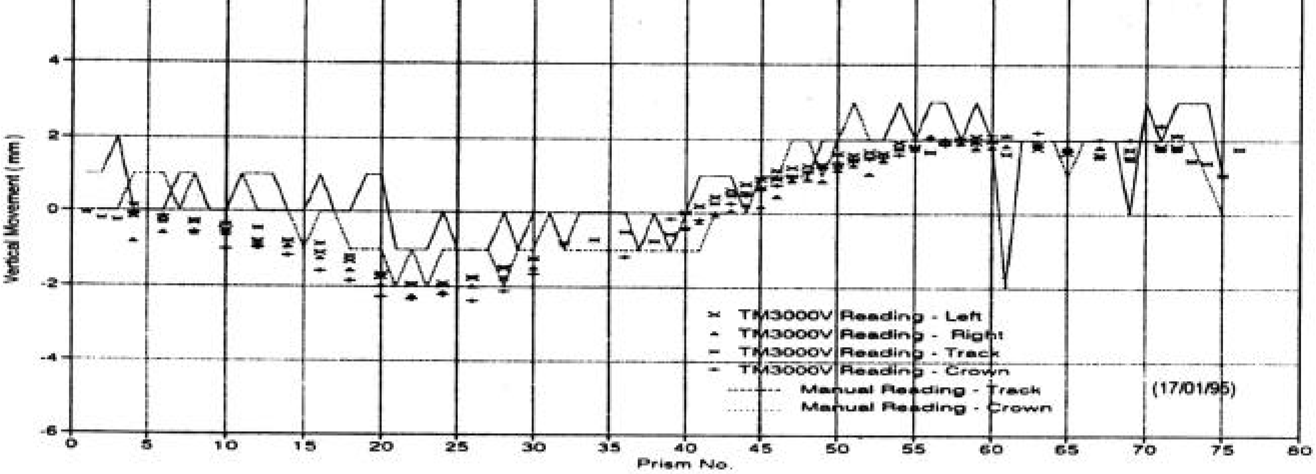

Fig. 13 Vertical movement readings recorded by TM3000V and manual survey at North Bound Tunnel

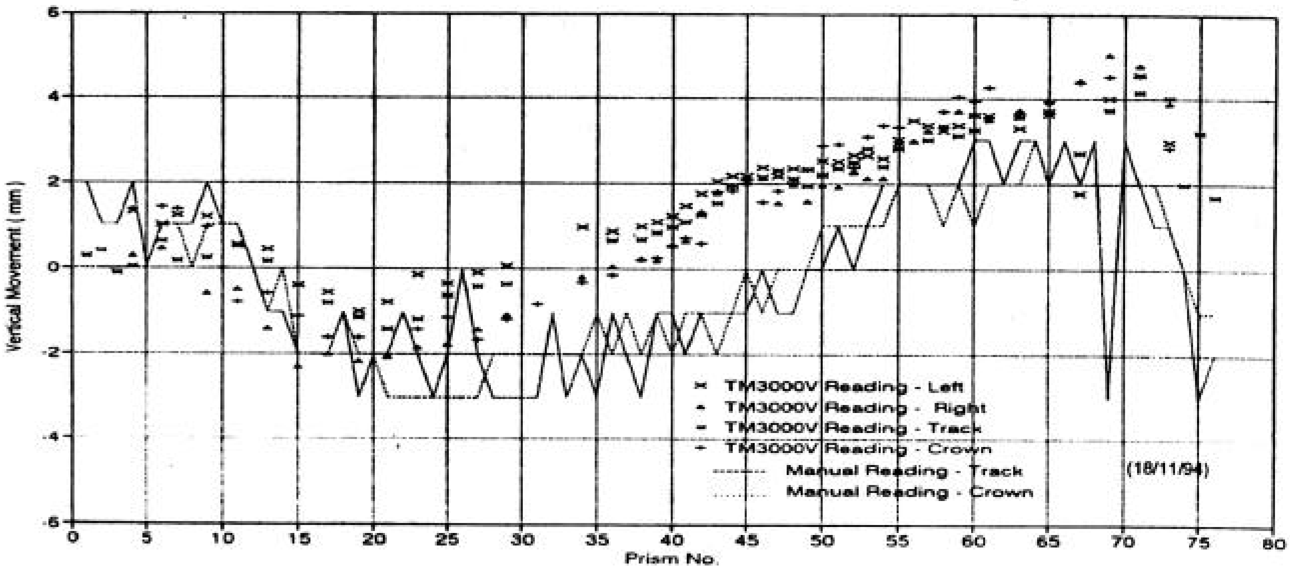

Fig. 14 Vertical movement readings recorded by TM3000V and manual survey at South Bound Tunnel

9 MONITORING OF MRT TUNNELS

Due to the road work involving cut and fill direct over the existing MRT tunnels, the behavior of the existing tunnels was closely monitored by automatic monitoring system (TM3000V) and manual survey during each stage of construction. The existing MRT line within the construction area was divided into three (3) zones, i.e. Zone A/Fill (CH66250-66450), Zone B/Cut (CH66450-66520) and Zone C/Cut (CH66520-66640) in view of the construction activities and soil condition.

Figures 13 & 14 show the trend of vertical movement readings of prisms (4 nos./section at 3 to 6m intervals) monitored by the TM3000V system in North and South Bound Tunnels, respectively. It can be clearly seen from these figures that downward movement in the fill zone and upward movement in the cut zone were recorded by the TM3000V for the two (2) existing tunnels during the construction of the proposed Irrawaddy Road with a max. movement value of 4.8mm and 7.3mm recorded at crown of the North and South Bound Tunnels, respectively. The movement readings of TM3000V are found to be higher than those recorded by Manual Survey (Figures 13 & 14). In general, the measured movement values of tunnels are smaller than the values predicated from simplified method using elastic solution (Table 3).

10 CONCLUSION

1) The wall deflection caused by excavation effect was found effectively controlled by the method of construction adopted and adequate rigidity of retaining system provided in the basement construction of the New Tan Tock Seng Hospital project.
2) The characteristic of wall deflection observed in the present case was found consistent with the relationship proposed by Moh et al (1999) with α values ranging from 39 to 201 which show good performance and less harmful effect to the adjacent structures.
3) The movement analysis using Oasys computer program "FREW" in term of effective stress method predicted the wall deflection reasonably well for the present case.
4) Ground settlement (i.e. max. 26mm, Ave. $87\pm40\%$ of lateral movement) induced by excavation effect was found confined within a distance of 2 times the excavation depth from the excavation boundary. The computed horizontal ground strains (i.e. 0.47×10^{-3} to 1.02×10^{-3}) and angular distortion (i.e. 0.73×10^{-3} to1.53×10^{-3}) at I-9/I-10 show very slight to slight damage effect (Boscardin, 1989) which is consistent with the response of the existing buildings and the low α values obtained in the present case.
5) In general, the tunnel movement values estimated from simplified method using elastic solution gave safe and reasonable prediction for the present case. The discrepancies between the predicted and measured tunnel movement could be attributed to i) compensating effect

due to groundwater table drawdown in cut zone, ii) possibility of higher elastic modulus of existing ground which was found with weathered rock at localized area and iii) stiffness of tunnel linings, which were not considered in the simplified analysis.

Table 3 Summary of Tunnel Movements

Location/ Construction Activities	Tunnel Movement, mm			Critical Location Considered
	Base	Crown	Sides	
1. Zone A (CH66350-66450) – Filling				
1.1 Prediction	+4.0	+6.9	-3.4	NB Tunnel
1.2 Automatic Survey (TM3000V)	+2.9	+4.8	-3.5	(Pt D / Prism Nos. 20 - 36)
1.3 Manual Survey	+2.0	+1.0	-3.0	("+" denotes settlement/inward)
2. Zone B (CH66450-66520) – Cutting				
2.1 Prediction	-4.8	-13.0	+5.4	NB Tunnel
2.2 Automatic Survey (TM3000V)	-2.8	-3.3	+4.0	(Pt C / Prism Nos. 54 - 55)
2.3 Manual Survey	-3.0	-3.0	+2.0	("-" denotes heave/outward)
2.4 Prediction	-3.0	-7.3	+3.1	SB Tunnel
2.5 Automatic Survey (TM3000V)	-5.2	-7.3	+5.5	(Pt J / Prism Nos. 54 - 55)
2.6 Manual Survey	-3.0	-3.0	+2.0	

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