SAFETY CONTROL FOR DEVELOPMENT ADJACENT TO EXISTING MRT STRUCTURES AND OBSERVED FIELD PERFORMANCE

S. K. Kong

Moh and Associates (S) Pte Ltd

Abstract: It is the great concern of the local authorities of Singapore in controlling the effects of adjacent construction activities on existing MRT structures for ensuring smooth operation and public safety. Code of Practice for Railway Protection has been implemented by the Development & Building Control (DBC) Department of Land Transport Authority (LTA), Singapore to safeguard the existing MRT structures against possible detrimental effects induced by any construction activities within the Railway Protection Zone. This paper describes the requirements to be complied by the engineers in the planning, investigation, design and construction of any development within the Railway Protection Zone. Precaution/protective measures commonly adopted in the construction control of selected projects and the behavior of ground and MRT structures observed by various types of instruments during adjacent construction works will be presented in this paper.

Keywords: MRT structures protection, codes & regulations, instrumentation.

1. INTRODUCTION

Similar to other modern cities in the world, high potential of land development along existing MRT lines are found in Singapore because of the convenience of commuting from the MRT system. In order to integrate the development with the MRT facilities for public convenience, deep basement adjoining to or direct above existing MRT stations are commonly involved in the new developments adjacent to existing MRT lines. Such construction activities may induce detrimental effects on the sensitive MRT structures if proper and adequate precaution/protection measures were not incorporated in the design and construction works.

2. SAFETY AND PROTECTION

2.1 Code of Practice for Railway Protection

In order to regularize and control the activities of new developments in close proximity to existing MRT structures, development sites located within the Railway Protection Zone (Figure 1) are subjected to the approval of Land Transport Authority (LTA) upon full compliance of the technical requirements (Figure 2) as specified in the Code of Practice for Railway Protection (2000). The Code limits movement of MRT structures due to adjacent construction to 15mm and rotation of the track to 1:1666 in any plane (Table 1). These values are

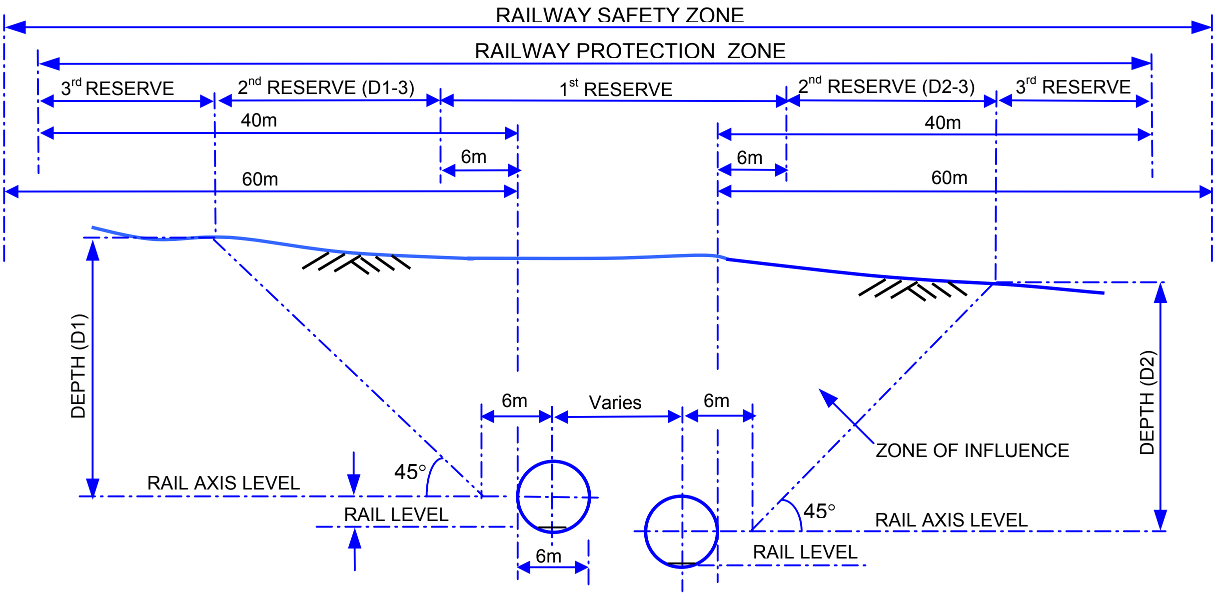

Figure 1 Railway Protection and Safety Zones (for underground MRT system)

seemed to be acceptable for any section of the existing MRT system, without any check of the actual condition of the structure or track. For special cases, the allowable limits may be adjusted according to the existing conditions of the tunnels and tracks and its design conditions (Doran, et al, 2000). As a protective measure, piles and diaphragm walls installed within 1st and 2nd Reserves (Figure 1) have to be debonded by proper means, such as permanent casings to minimize possible stress effect induced by the proposed piles on the existing MRT structures.

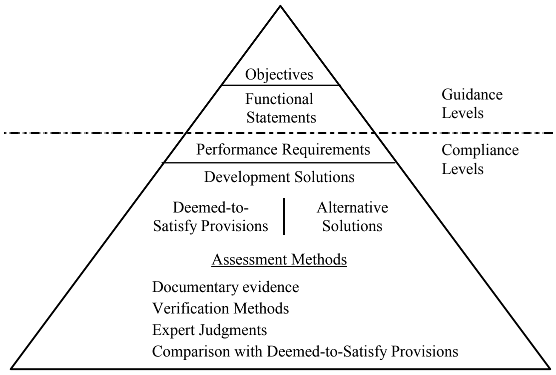

Figure 2 Structure of Technical Requirements

2.2 Planning/Design Consideration

For any new developments located within the Railway Protection Zone, necessary permits from LTA must be obtained by Qualified Person (QP) prior to the commencement of construction works within the restricted zones. Engineering evaluation report to justify the fulfillment of allowable limits (Table 1) including method statement of work, instrumentation proposal and review levels for the various instruments are needed to be submitted by QP for LTA's approval during planning/design stage. Design of foundations within the Railway Protection Zone shall incorporate all necessary measures to ensure the safety of the existing MRT structures.

3. CONTROL OF SITE ACTIVITIES

Site activities within Railway Protection Zone including site investigation works are strictly controlled by the DBC of LTA and can only be proceeded after permission is granted by the Authority. For preventing possible damage to existing MRT structures, especially the underground tunnels, exploration and foundation works are generally not allowed in 1st Reserve except for very special cases.

3.1 Field Exploration Works

Drilling of boreholes located within 2nd Reserve are subjected to the verification of hole co-ordinates by Project Surveyor and LTA Surveyor after approval is granted by LTA. Centrelines of existing tunnels are also needed to be pegged out at site for inspection of LTA Safety Officer prior to the commencement of drilling works within 2nd Reserve. All the drilled holes are required to be backfilled with cement-bentonite slurry upon completion.

3.2 Construction Works

According to "Guide to Carrying Out Restricted Activities within Railway Protection and Safety Zones" produced by the DBC of LTA, the movement of heavy construction plants, such as mobile crane/tower crane and drilling/piling equipment are strictly controlled at a safe distance away from existing MRT structures (Figure 3) under the supervision of qualified lifting supervisor and safety officer. Crane or machinery may be allowed to encroach in 1st Reserve for special case provided that regular inspection and full time supervision by PE(Mech) and PE(Civil), respectively, are provided.

4. PROTECTIVE MEASURES

In order to minimize possible detrimental effect induced by adjacent construction works on existing MRT structures, especially for the critical environment involving deep excavation in thick soft clay, proper protective measures are essential in ensuring the safety of the MRT structures. Common types of protective measures adopted in the construction works near existing MRT structures in Singapore include :

(1) Rigid retaining structures and proper construction method, e.g. diaphragm wall and

Table 1 Allowable Limits for Existing MRT Structure and Track

Type of MRT Structure		Structure						Track		
		Imposed Load (kPa)			Movement (mm)		Peak Particle Velocity (mm/sec)	Twist/ Change in Cant (a)	Vertical Dip or Peak (b)	Horizontal Versine (c)
		Under Roadway		Not Under Roadway	Total Movement in any Direction	Differential Movement in any Plan				
		≤1.5m	>1.5m							
Under ground	Tunnel & Station	#	15	15	15	15 or 1:1000*	15	1.5mm+ or 1:1666	5mm+	15mm+
Above Ground	Viaduct	15	15	15	15	15 or 1:1000*	15	As above	As above	As above
	Station					5				
At Grade	Embank-ment	-	-	40 **	15	15 or 1:1000*	15	As above	As above	As above
	Cutting	-	-	15 **						

\# HA loading or 45 units of HB loading dispersed in accordance with BS5400 Part 2 and HB vehicle placed within the central 5m of the carriageway and no HA loading in combination with the HB vehicle.

+ Measured over 2.5m (a), 5m chord (b) & 15.8m chord (c), * whichever is lesser ** outside 1st Reserve

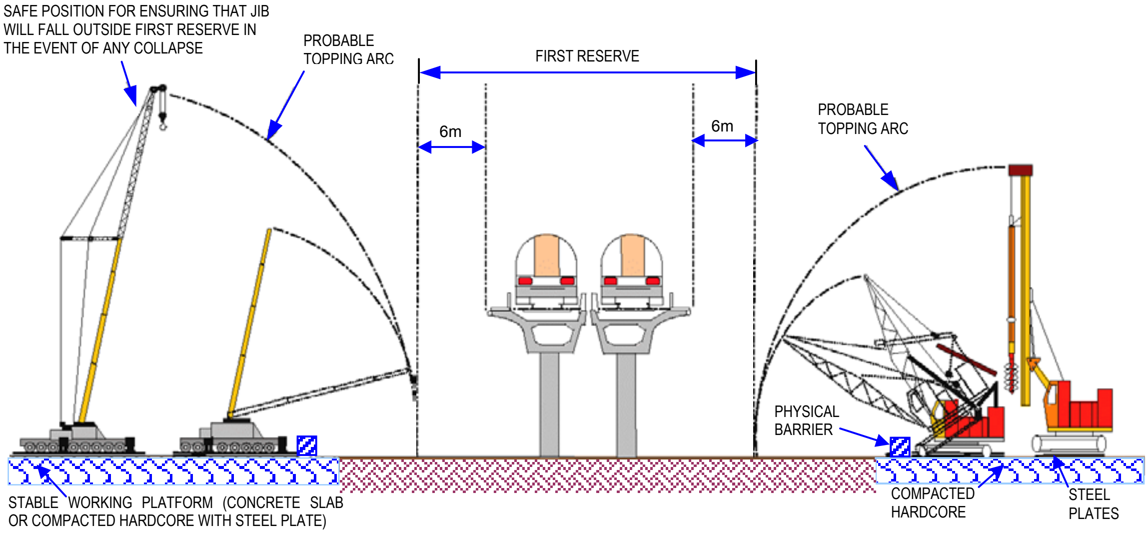

Figure 3 Control of Mobile Crane, Drilling or Piling Equipment

top-down construction method;

(2) Good water-tight retaining structures and water recharging wells;
(3) Soil improvement technique, e.g. jet grout slab;
(4) Debonding of pile and diaphragm wall in 1st & 2nd Reserves
(5) Silent piler

Figure 4 shows a typical profile of the protective measures (i.e. top-down construction with jet grout slabs) adopted in deep basement construction works carried out in soft Marine Clay adjacent to existing MRT tunnels.

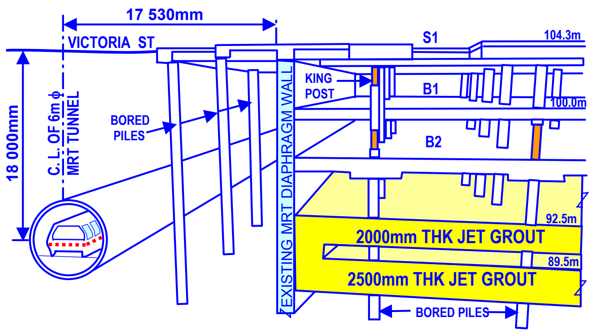

Figure 4 Excavation Near Existing MRT Tunnels

5. INSTRUMENTATION

In order to protect the existing MRT system against risks posed by restricted activities arising from any development within the Railway Protection Zone, proper instrumentation monitoring system is essential in i) obtaining necessary permits from LTA, ii) verifying field performance and iii) ensuring the safety of MRT system during each stage of construction. Instrumentation system planned in accordance with the code requirements (Table 2) are required to be properly installed, monitored and regularly submitted to LTA for review during the entire construction period. Among the various types of instruments adopted in the MRT monitoring, an automatic monitoring system using a 3-D Total Station (Figure 5) which allows continuously monitoring of tunnel condition at all hours throughout the day and night has been successfully applied in the safety monitoring since 1992 in Singapore (Chua et. al. 1999). Such system overcomes problems associated with restricted access to tunnels commonly encountered in the manual survey of tunnel alignment and has become a necessary system for safety monitoring of existing MRT tunnels near construction sites in Singapore.

Table 2 Provision of Instrumentation for Construction Activities within the Railway Protection Zone

Type of Instruments		Foundation Works					Excavation Works				
		For Underground, Transition, Sub-aqueous & At Grade Structures			For Above Ground Structure		For Underground, Transition, Sub-aqueous & At Grade Structures			For Above Ground Structure	
		1st Reserve	2nd Reserve	3rd Reserve	1st Reserve	Outside 1st Reserve	1st Reserve	2nd Reserve	3rd Reserve	1st Reserve	Outside 1st Reserve
In Ground	Inclinometer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Water Standpipe	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Piezometer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Settlement or Heave Marker	x	x	x	x	x	Yes	Yes	x	Yes	x
On MRT Structure	Automatic Trainway Monitoring System	See Note 1 below			x	x	See Note 1 below			x	x
	Manual Survey	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Tiltmeter	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Vibration Sensor	Yes	Yes	See Note 2 below			Yes	Yes	See Note 2 below		
	Crackmeter	Required if there are existing cracks that are likely to be aggravated by the development works or where works affects tunnel and station interface									

Notes : (1) Required if predicted cumulative movement of MRT structures due to all construction activities within the railway protection zone exceeds 5mm
(2) Required if method of work is likely to generate any vibration at the rapid transit systems structure

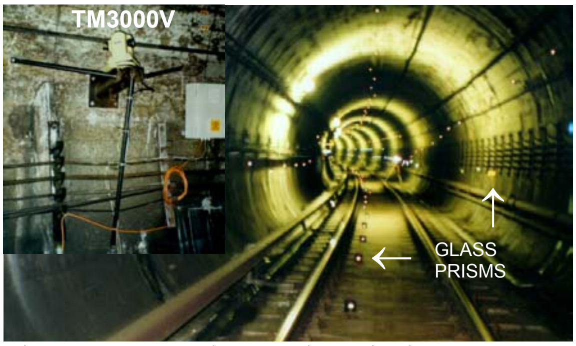

Figure 5 Automatic Tunnel Monitoring System

6. CASE STUDY

6.1 General

The New Tan Tock Seng Hospital (TTSH) located in close proximity to sensitive existing structures, e.g. MRT tunnels and hospital ward has been successfully completed through the proper planning, design, geotechnical inputs and application of suitable construction method and instrumentation system. M/s Moh and Associates (S) Pte Ltd was the Geotechnical Consultant of the project and also the Geotechnical Consultant to Main Contractors with owner's consent in view of the sensitive environment and the complicated geology. The development involved the construction of 3 to 4-level basement (down to 16.5m) in close proximity to the existing MRT tunnels and a 6-storey hospital ward block resting on footings and a new road built by cut & fill method over the existing tunnels (Figure 6). A rigid retaining system consisting of contiguous bored pile (CBP) walls supported by ground anchors and rakers was adopted in the basement excavation works for minimizing possible effects to the sensitive environment.

6.2 Subsoil Condition

The project site is 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 the north-west and 1.5~6.0m in the north-east area. 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.

6.3 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 (Figure 6) has been implemented for the safety control of existing MRT structures and construction works of this project.

6.4 Wall Deflection

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 7 & 8 show the change of lateral movement at selected depths recorded by Inclinometer Nos. I-5 and I-9, respectively, during excavation and substructure construction stages. As indicated these figures, the wall deflections increased rapidly with depth of excavation and tended to stabilize after the excavation was

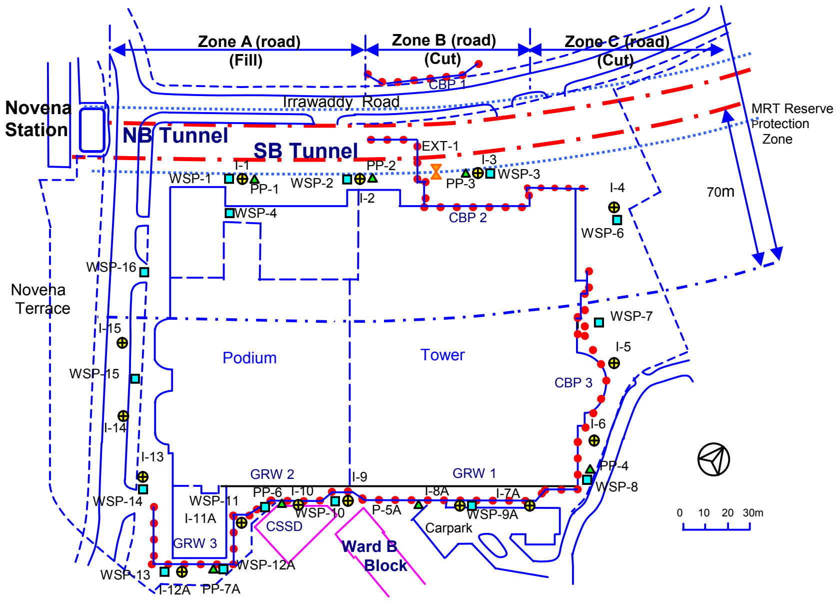

Figure 6 Site and Instrumentation Plan (TTSH)

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

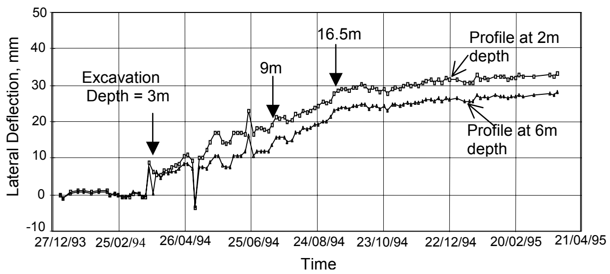

Figure 7 Change of Lateral Movement (I-5)

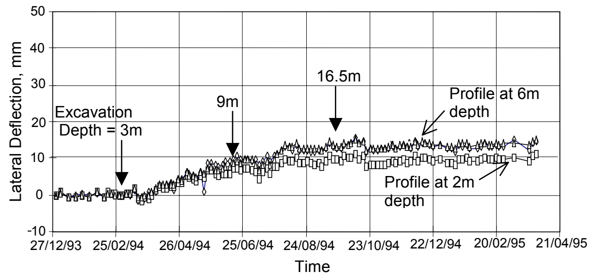

Figure 8 Change of Lateral Movement (I-9)

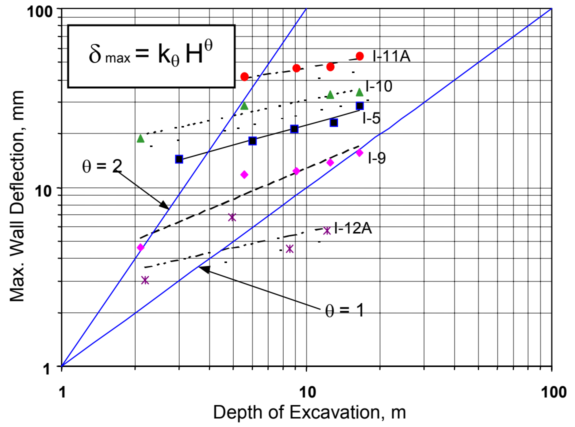

Figure 9 Wall Deflections versus Excavation Depth

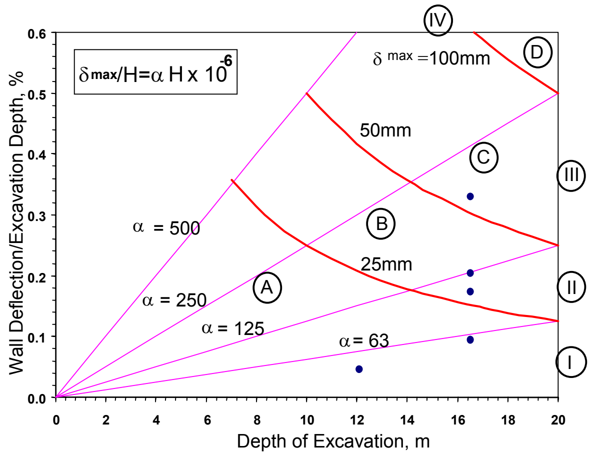

Figure 10 Wall Deflections in Jurong Formation

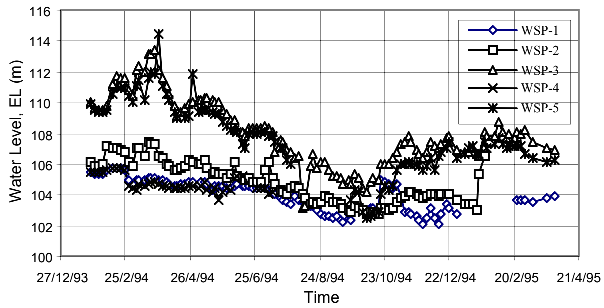

Figure 11 Groundwater Level Observation

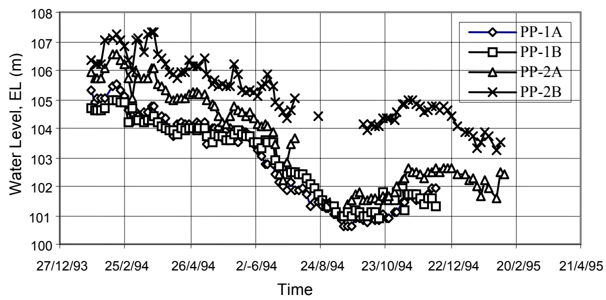

Figure 12 Piezometric Level Observation

completed and adequate supports were provided. Effect of disturbance caused by earth compaction plant was found in these two (2) instruments which were in close proximity to the road construction zones. Figure 9 shows the "characteristic curves" (Moh et al 1999) for wall deflections and Figure 10 shows a plot of normalized wall deflections versus depth of excavation for the present case with α value ranging from 39 to 201. The lateral ground movement was under well control with a maximum movement value of 54.6mm (I-11A) and 25.8mm (I-3) recorded at excavation boundaries near the existing Ward B Block and MRT tunnels, respectively.

6.4 Groundwater/Piezometric Levels

Monitoring results (Figures 11 & 12) of water standpipes and piezometers indicate that the groundwater levels declined steadily during excavation and stabilized after earthwork activity was completed.

6.5 Monitoring of MRT Tunnels

Due to the road work over the existing MRT tunnels involving cut and fill, 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 zones, i.e. Zone A/Fill (CH66250 - 66450), Zone B/Cut (CH66450 - 66520) and Zone C/Cut (CH66520 - 66640) in view of the type of construction activities and soil conditions.

Figures 13 & 14 show the trend of vertical movement readings of the glass 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 existing tunnels during construction of the Irrawaddy Road with a maximum movement value of 4.8mm and

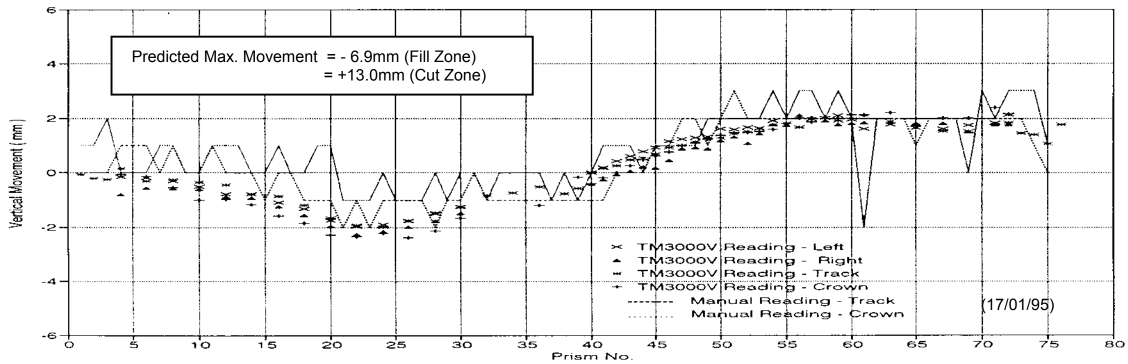

Figure 13 Vertical Movement Readings recorded by TM3000V and Manual Survey at North Bound Tunnel

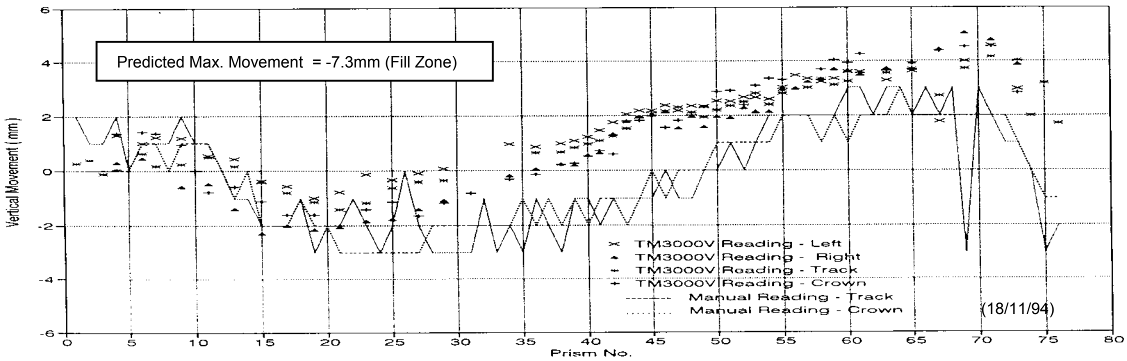

Figure 14 Vertical Movement Readings recorded by TM3000V and Manual Survey at South Bound Tunnel

and 7.3mm recorded at the crown of North and South Bound Tunnels, respectively. The movement readings of TM3000V are found to be consistent with those recorded by Manual Survey. In general, the measured movement values of tunnels are found smaller than the predicted values which 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 analysis.

7. CONCLUSIONS

(1) Good planning & control system consisting of Codes, Guidelines and proper procedures are essential in ensuring successful execution of new developments near existing MRT structures and maintaining public safety. The establishment of allowable limits by local authorities based on design conditions and field performance provide a useful guide to the engineers/contractors of these critical projects.

(2) Construction activities within Railway Protection Zone shall be regularized and controlled by the Code of Practice and executed under the supervision of competent engineers for minimizing detrimental effect on existing MRT structures.

(3) The effect of construction on the existing MRT structures shall be properly evaluated by necessary analyses in the design and verified by suitable instrumentation system during construction.

(4) The application of suitable protective measures, e.g. rigid retaining system, soil improvement technique, special equipment and advanced automatic monitoring systems are found with significant contribution to the safety control of underground MRT structures in close proximity to construction sites in view of its sensitivity and restricted accessibility. However, proper interpretation of instrument readings, application of good engineering judgement and supervision by competent geotechnical engineers are needed.

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Synopsis

Four major infrastructure projects in Taipei and Bangkok were discussed to illustrate the importance of geotechnical engineering in any infrastructure development in terms of safety and economy. The four projects are the Taipei Rapid Transit Systems, the Taipei Airport Underpass, the Bangkok-Chonburi New Highway and Ground improvement of the Second Bangkok International Airport. They were selected not only because of the mega size in terms of construction cost but also because of the complexity or uniqueness of the project. Emphasis has been placed on the importance of adequate and reliable subsurface information, appropriate selection of analysis principles and construction methodology/details, ability to copy with variation in ground conditions and timely interpretation of field performance data.