Under the Royal Patronage of His Majesty the King

Organized by :

The Engineering Institute of Thailand
Chulalongkhon University

- Department of Civil Engineering
- Department of Environmental Engineering
- Department of Survey Engineering
- Department of Water Resources Engineering

In Corporation with :

Department of Civil Engineering from Universities in Thailand

Engineering for Sustainable Development

Proceedings of the Seventh National Convention on Civil Engineering

Monitoring of diaphragm wall displacement and associated ground movement, brace excavation adjacent to historical building at the bank of Chao Phraya River

Pornpot Tanseng
Suranaree University of Technology, Nakornratchasima, Thailand

Zaw Zaw Aye and Chanchai Submaneewong
SEAFCO Co., Ltd., Bangkok, Thailand

ISBN 974-13-0107-3

การตรวจวัดการเคลื่อนตัวของกำแพงชนิดขุดเจาะและการเคลื่อนตัวของดินที่เกิดจากงานขุดดินใกล้อาคารประวัติศาสตร์ริมฝั่งแม่น้ำเจ้าพระยา

MONITORING OF DIAPHRAGM WALL DISPLACEMENT AND ASSOCIATED GROUND MOVEMENT, BRACED EXCAVATION ADJACENT TO HISTORICAL BUILDING AT THE BANK OF CHAO PHRAYA RIVER

Pornpot Tanseng[1], Zaw Zaw Aye[2] and Chanchai Submaneewong[3]

[1]Lecturer
Suranaree University of Technology, Nakornratchasima, Thailand

[2]Project Manager, [3]Geotechnical Engineer
SEAFCO Company Limited, Bangkok, Thailand

บทคัดย่อ: อาคารสมัยใหม่ที่ก่อสร้างในพื้นที่กรุงเทพมหานครจำนวนมากมักจะออกแบบให้มีชั้นใต้ดินอยู่ใกล้กับอาคารหรือสิ่งก่อสร้างเดิม การขุดดินฐานรากของอาคารต่างๆ ดังกล่าวโดยใช้กำแพงกันดินชนิดขุดและหล่อคอนกรีตในดิน (Diaphragm wall) ได้รับความนิยมอย่างแพร่หลายเนื่องจากเป็นระบบป้องกันดินที่สามารถปรับเปลี่ยนเป็นโครงสร้างถาวรได้ ภายหลัง การก่อสร้างจะต้องมีการตรวจวัดการเคลื่อนตัวระหว่างการขุดอย่างเป็นระบบ โดยเฉพาะอย่างยิ่งในกรณีที่ต้องขุดใกล้กับโครงสร้างเดิมที่สำคัญและโครงสร้างที่เกิดการเคลื่อนตัวง่าย บทความนี้จะนำเสนอระบบการตรวจวัดการเคลื่อนตัวของกำแพงชนิดขุดและหล่อคอนกรีตในดินและการทรุดตัวของดินบริเวณด้านหลังกำแพงและบริเวณอาคารเก่าข้างเคียงรวมถึงอาคารประวัติศาสตร์โดยใช้อุปกรณ์เครื่องมือวัดหลายชนิดในงานขุดเพื่อก่อสร้างห้องใต้ดินริมฝั่งแม่น้ำเจ้าพระยาซึ่งเป็นงานขุดดินในสภาวะที่มีแรงดันดินไม่สมดุลย์ (Unbalanced loading condition) และได้ทำการประเมินความเสี่ยงต่อความเสียหายต่ออาคารข้างเคียงจากข้อมูลการวัดการเคลื่อนตัวที่วัดได้จริงเปรียบเทียบกับกฎเกณฑ์ที่เสนอไว้ในงานวิจัยก่อนหน้า รวมทั้งนำเสนอการปรับเปลี่ยนขั้นตอนการก่อสร้างให้สามารถทำการตรวจวัดการเคลื่อนตัววิกฤตได้ตลอดเวลา

ABSTRACT: Modern buildings in Bangkok frequently require the excavation works for the basement facility adjacent to the existing structures. Diaphragm walls have been commonly used as permanent retaining walls for excavation works in various projects. Comprehensive monitoring system is of essential for any excavation works particularly for those adjacent to the sensitive buildings. This paper presents the monitoring of diaphragm wall displacement and associated movement of the ground and adjacent structures including historical building using a number of instruments for basement construction works located at the bank of Chao Phraya River. The bracing system and construction sequence adopted for excavation with the consideration of the presence of an unbalanced loading condition are also briefly discussed. Building damage risk assessment using a simple approach was carried out based on the instrumentation results and compared with the damage criteria established by published research work. A course of action undertook in response to the observed critical movement is also presented.

KEYWORDS: Diaphragm wall, Instrumentation, Unbalanced Loading

For further details, contact Mr. Zaw Zaw Aye, SEAFCO Co., Ltd. 26/10 Prayasuren Road, Bangchan, Khlong Sam Wah, Bangkok 10510, Thailand

1. INTRODUCTION

Excavation works in soft ground inevitably induced the ground movements which in turn may damage the adjacent existing structures. Diaphragm walls are commonly used as permanent retaining walls for basement excavation of many projects in Bangkok. It is necessary to use this type of rigid retaining wall in excavation work to minimize the ground movement particularly where the work is to be carried out in close proximity to the existing sensitive buildings. This paper presents the monitoring of diaphragm walls displacement and associated movement of the ground and the adjacent structures including historical building using a number of instruments for completed construction works located at the bank of Chao Phraya River, Bangkok. Design and construction aspects of the project have been reported by Thasnanipan et al. (1999).

2. PROJECT LOCATION AND CONSTRAINTS IMPOSED ON SITE

The project is situated in the heart of an old established culturally-significant area. The project consisted of basement excavation works for two separate buildings with the support of braced diaphragm walls.

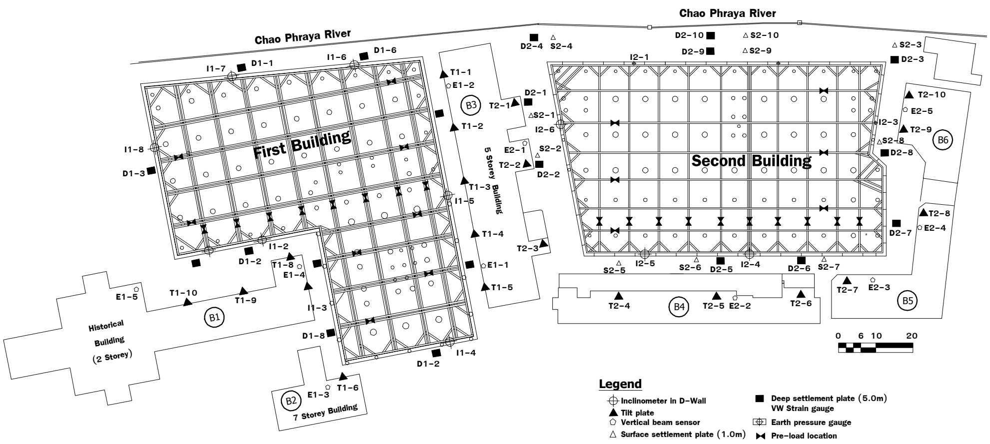


Figure 1 Layout of excavation sites and instrumentation

Two basements are located 40m apart, separated by an existing 5 storey building. As shown in Figure 1, construction site is located along the bank of Chao Phraya River and surrounded by existing buildings including a historical building. Along the river, the distance between diaphragm walls and existing old river wall is about 4m and 8m for the first and second buildings respectively. Locations of the excavation sites themselves posed some constraints, which called for the need of careful consideration in establishing the design principles and sequence of construction. The major constraints imposed on sites are outlined below.

2.1 Loading condition

Thasnanipan et al. (1999) reported the presence of unbalanced loading condition. As the excavation areas are located immediately next to the river and surrounded by existing buildings, the walls alongside the river and the opposite walls were particularly expected to undergo an unbalanced lateral loading condition. No case history data of similar condition in the area were available at the time of design and construction of the basements.

2.2 Risk of damage to the existing buildings

The existing buildings located in the proximity of the excavation areas are of old structures. According to the available information, the buildings are supported by the piled foundation. However, no detailed information such as type, size and length of the piles was available. The most critical structure is the historical building which is a predominantly masonry and only 5m away from the outer face of the diaphragm wall of the first excavation site. As the building is important for its historical heritage, a damage category worse than negligible (as defined by Rankin 1988) would not be acceptable.

3. SUBSOIL INVESTIGATION

Two stages of site investigation were made. Preliminary stage of site investigation was performed during the tendering stage. Second stage of soil investigation was conducted prior to designing temporary bracing and basement excavation work. As subsoil properties obtained from the boreholes and test data were well reported by Thasnanipan et al. (1999), they are not presented again in this paper.

4. DIAPHRAGM WALL AND BORED PILES

For both buildings, 800mm thick cast in-situ concrete diaphragm walls of 28m toe depth with two level temporary bracings were designed for basement excavation. The maximum excavation depths for the first and second buildings were 12.7m and 9.7m respectively. Deep diaphragm walls of toe depth 28m were necessary to ensure the overall stability considering the location of the basement excavation at the bank of the river. Bored piles of diameter ranging from 800mm to 1500mm founded at 48m depth were constructed by wet process using bentonite slurry.

5. INSTRUMENTATION AND MONITORING PROGRAM

Instrumentation played major role in this project. The primary objective of the instrumentation program was to monitor the performance of the excavation to ensure that diaphragm wall as well as the entire excavation system were stable and that adjacent structures were not adversely affected. Furthermore, the instrumentation program was established to provide the main feedback in application of observational method. Types of instrumentation used in the project are presented in Table 1. Layouts of instrumentation for the first and the second buildings are shown in Figure 1.

Table 1 Quantity of Instrumentation and parameters measured

Type of Instrumentation	First Building	Second Building	Monitored Parameters
Inclinometer	8	6	Wall deflections
Settlement Plate	10	20	Ground settlements
Tiltmeter	10	10	Tilting of Buildings
Vertical Beam Sensor	5	5	Tilting of buildings
VWSG	-	1 location*	Strain in rebars
Earth Pressure Gauge	-	2 x 2	Strut forces

* A pair of VWSG in 5 layers along the depth of wall panel

6. EXCAVATION METHOD AND BRACING SYSTEM

Conventional bottom–up method with two levels of temporary bracing was applied for both buildings excavation. As reported by Thasnanipan et al. (1999), to prevent adverse wall behavior alongside the river due to the presence of unbalanced lateral loading condition, pre-loading was applied at one end of struts on the land side wall with simple and efficient temporary bracing system. As the excavation work of the first building was completed 1 year before the commencement of the second building, monitoring results of the first excavation work provided an ample opportunity to review the design assumption and fine tune the parameters used in the analysis of the diaphragm wall for the second building. The major modification was to use single strut for the first level of the second building (less rigid but economical compared to that of the first building) with the provision of strut-force monitoring, according to Thasnanipan et al. (1999). Summarized information of excavation and bracing systems of two buildings is tabulated below.

Table 2 Summary of excavation and bracing systems

Building	Excavation Depth	Bracing Level	Bracing Elevation	Strut Sections	Design Strut Force kN/m
First	-12.79m	I	-2.0	2 x WF350 x 350	484.0
		II	-6.5	2 x WF400 x 400	789.0
Second	-9.70m	I	-2.0	1 x WF400 x 400	279.4
		II	-7.0	2 x WF350 x 350	332.1

7. SETTLEMENT PREDICTION

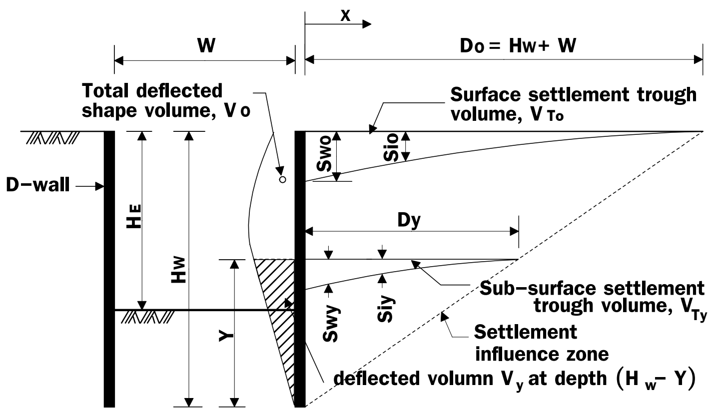
Due to the presence of unbalanced loading condition, non-symmetric pattern of settlement distribution around the perimeter of excavation could be expected. However, considering the fact that pre-loading was to be used for the land side diaphragm wall but not for the riverside wall, settlement distribution was assumed to be symmetrical. Available methods were reviewed for predicting the ground movement with the consideration of two main factors such as, (1) simple and practical in application (2) enable to correlate with the predicted and measured diaphragm wall deflection.

7.1 Prediction of Surface Settlement

The method proposed by J. E. Bowels (1990) was selected as it meets the required criteria mentioned above. Bowels suggested the ground settlement induced by excavation as a function of ground loss due to the deflection of the retaining wall. Bowel demonstrated the calculation of settlements at specified distance by assuming parabolic variations of settlement within the influence distance. Using predicted diaphragm wall deflection, surface settlement behind the wall was computed by empirical formulas proposed by Bowels.

7.2 Prediction of Sub-surface Settlement

A simplified prediction of sub-surface settlement was made based on the calculated surface settlement described above. First, subsurface settlement influence line was constructed. As shown in Figure 2, settlement influence zone is assumed to decrease with depth from "D_o" at the surface and zero at the wall toe. With the assumption of linear relationship between the volume of deflected wall shape and the volume of settlement trough at any depth within settlement influence zone, subsurface settlement at different depths were calculated.



$$S_{WO} = \frac{4V_O}{D_O}$$

$$S_{io} = S_{WO} * \left(\frac{x}{D_O}\right)^2$$

$$D_Y = Y * \frac{D_O}{H_W}$$

$$V_{TY} = V_Y * \frac{V_{TO}}{V_O}$$

Figure 2 Demonstration of settlement prediction from diaphragm wall deflection values

8. INSTRUMENTATION RESULTS

8.1 Inclinometer Monitoring

The predicted and observed diaphragm wall deflections of the first building and second buildings are presented in Figure 3a and 3b respectively. As can be seen in the figures, observed wall movements exceeded the predicted values at the top portion of the walls for both buildings. The delay in installing the first level bracings, leaving the walls in cantilever conditions for the long period was the main reason of the large movement induced by the excavation at that stage.

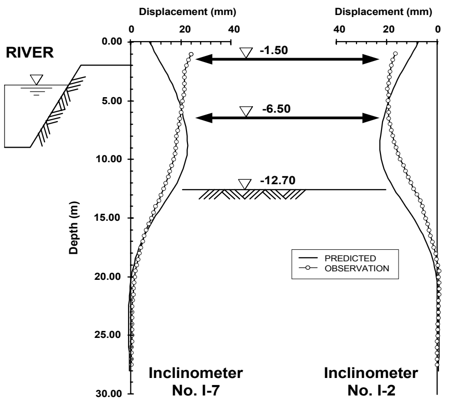


Figure 3a. Lateral wall movements (1st Building)

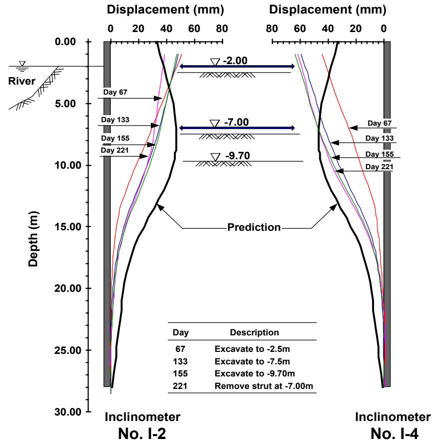


Figure 3b. Lateral wall movements (2nd Building)

At Inclinometer No.I-6 of the second building, wall movement was found to reach the trigger value at top portion when excavation reached 7.5m depth after the first level bracing installation. Lateral wall movement reached a maximum rate of 6.5mm/day and a tension crack on the ground was found about 8m away from the wall. A close examination of the bracing system indicated that one strut had swayed slightly about 130mm. Immediate actions were taken by stacking additional strut on the defective one and installing of the second level bracing carried out at that area. The wall movements were found to cease after these actions.

The wall deflections of the first building excavation found unaffected by the unbalanced lateral loading condition. However, for second building, monitoring results from inclinometer I-2 and I-4 suggested that the wall alongside the river was pushed against the retaining soil by the opposite wall.

8.2 Settlement and Building Movement

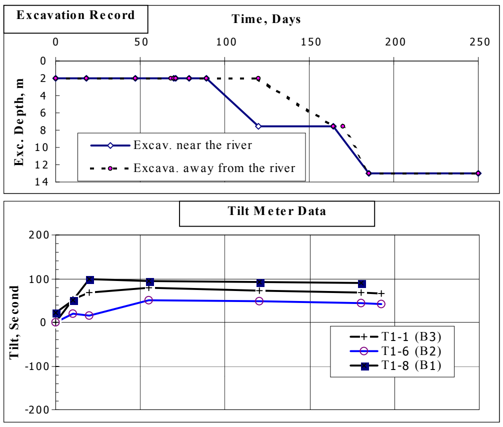
Figures 4a, 4b and 4c present the construction activities with time and corresponding monitoring data. As can be seen in the figures, monitoring results reflected the construction activities in general. It was also proved that performance and response of the diaphragm wall were largely influenced by the construction activities. It can be observed that significant changes in the responses were mainly occurred during the initial excavation stages in which walls were unsupported for long period. Monitoring data particularly that of settlement and building tilt measurement provided ample opportunity to assess the risk of the existing buildings damage. As the measured data were far less than the critical values, the excavation works were proceeded with confidence.

8.3 Strut Force Measurement

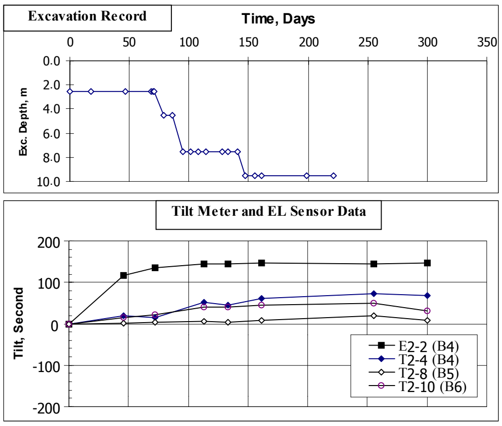
Daily monitoring was carried out for pressure gauges installed on struts. The comparison of predicted and measure strut forces are presented in Table 3. In general, the measured values indicated that the bracing system used was adequate.

Table 3 Comparisons of Predicted and Measured Strut Force

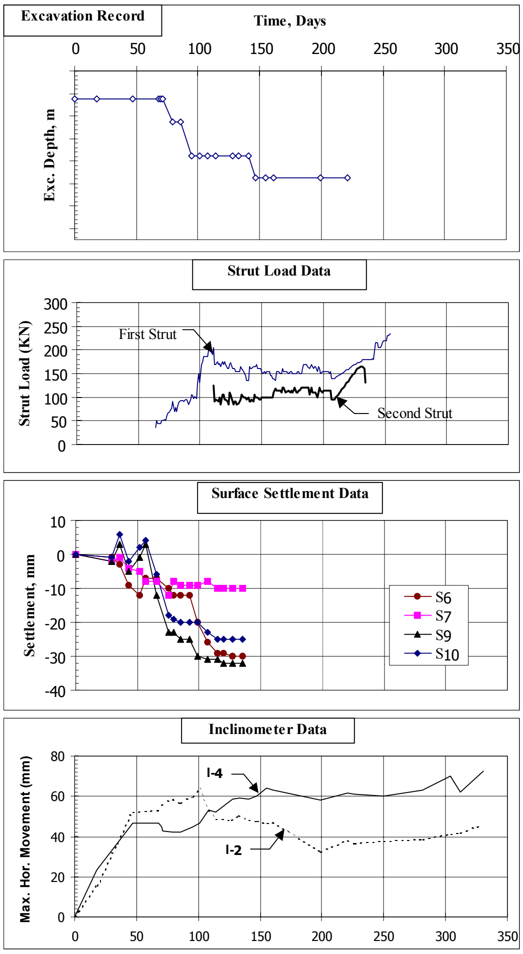
Bracing Level	Predicted Force (KN/m)	Measured Force (KN/m)
First Level	354.5	331.3
Second Level	307.3	206.3



a) Tilt meter results with construction time (1st Building)



b) Tilt meter results with construction time (2nd Building)

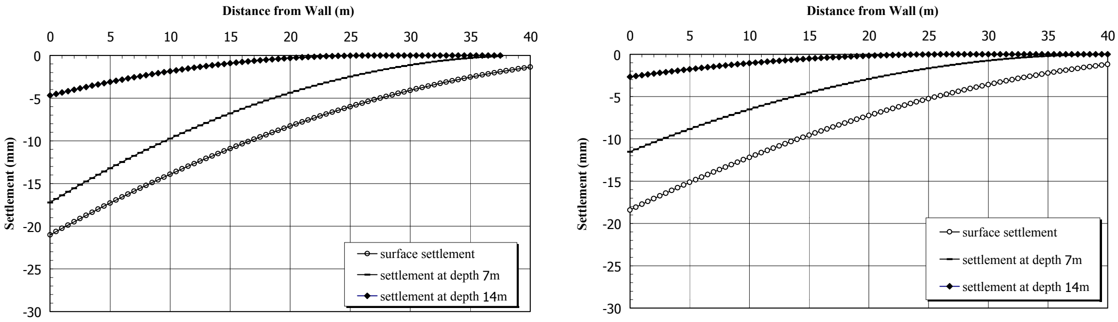


(c) Strut load, settlement and max. wall movement with construction time (2nd Building)

Figure 4 Monitoring results of instruments with construction time for First and Second Buildings

9. BUILDING DAMAGE RISK ASSESSMENT

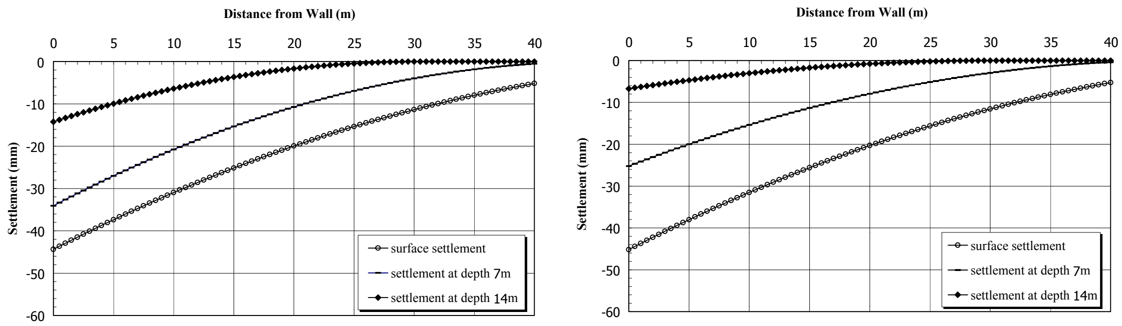
A simple approach was adopted for building damage assessment. Settlement and slope of the buildings due to the excavation works were predicted assuming the “green filed” condition. Neglecting restraints from foundation and structure, it was assumed that buildings follow the ground settlement trough at foundation level (estimated pile tip level). Using predicted and measured deflection values of diaphragm walls, surface and subsurface settlement profiles were prepared as shown in Figures 5 and 6. Building slopes likely to be induced by differential settlement were then predicted as presented in Table 4.



a) From predicted deflection values

b) From measured deflection values

Figure 5 Prediction of surface and subsurface settlement induced by 1st building excavation



a) From predicted deflection values

b) From measured deflection values

Figure 6 Prediction of surface and subsurface settlement induced by 2nd building excavation

Table 4 Predicted Building Slope Calculated from D-Wall Deflection

Building No.	Depth of Settlement Considered*	Predicted Building Slope Calculated from D-Wall Deflection		Maximum Tilt Measured by Tilt Meter / EL Beam	Building Slope Criteria for Negligible Damage**
		From Prediction	From Inclinometer Measurement		
B1	At surface	1/1778	1/2000	1/2082	< 1/500
	At depth 5m	1/1778	1/2133		
B2	At surface	1/1583	1/1827	1/4125	< 1/500
	At depth 7m	1/1583	1/2879		
B3	At surface	1/1563	1/1667	1/2578	< 1/500
	At depth 7m	1/1667	1/2778		
B4	At surface	1/880	1/880	1/1412	< 1/500
	At depth 7m	1/978	1/1257		
B5	At surface	1/944	1/1700	>1/5000	< 1/500
	At depth 14m	1/1771	1/4250		
B6	At surface	1/926	1/926	1/3437	< 1/500
	At depth 14m	1/2256	1/4400		

Note : (1) * assumed foundation level (2) ** unlikely to have superficial damage (Rankin 1988)

As can be seen in Table 4, the measured maximum tilt of the buildings reasonably agree with predicted building slopes derived from inclinometer measurement, particularly if the buildings were assumed to be settled by subsurface settlement at assumed pile tip levels. All buildings were predicted to be in negligible risk category as classified by W.J. Rankin (1988). Field inspection confirmed that no damage was caused in all buildings from the minor movements induced by excavation works.

10. CONCLUSIONS

Instrumentation played a major role in execution and successful completion of excavation works adjacent to the existing sensitive buildings under unbalanced loading condition. Effective bracing system, excavation sequence and adequate embedment of the retaining walls were the main factors contributed in minimizing negative impact of the unbalanced loading condition.

A simple approach in prediction of ground settlement and assessment of the risk of building damage has been presented. The measured maximum tilt of the buildings reasonably agreed with the predicted values. It is necessary to use the rigid diaphragm wall in excavation work to minimize the ground movement particularly where the work is to be carried out in close proximity to the existing sensitive buildings.

REFERENCES

1. Bowels J.E., Foundation Analysis and Design, 4th Edition, McGraw-Hill, Singapore, 1990.
2. Rankin W.J., Ground Movement Resulting from Urban Tunnelling : Prediction and Effects, Engineering Geology Special Publication No.5, p. 79-92, 1988.
3. Thasnanipan, N., Maung A. W., Tanseng P. & Teparaksa W., Behavior and Performance of Diaphragm Walls under Unbalanced Lateral Loading along the Chao Phraya River , Field Measurements in Geomechanics, Leung, Tan & Phoon (eds), p. 267-272, Balkema, 1999.