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A Comparative Study for Behavior of Strutted D-Walls under Asymmetric Lateral Loading along the Chao Phraya River Formation

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Abstract:*The main aim of this comparative study is to determine the effects of unsymmetrical lateral loaded braced diaphragm wall in Chao river formation, on lateral displacement of diaphragm wall and forces in struts. In this study a symmetric 2-D finite element analysis model for the case under study was carried out using Plaxis finite element computer program using Mohr-Coulomb and Hardening Soil constitutive models. The study showed that the unbalanced loading condition resulting from the existence of river slopes in one side of the excavation cause a different horizontal displacements values for both diaphragm walls. Also, the predicted values of horizontal displacement of the diaphragm wall using MC model were more near to the field measured values than those extracted from HS model.*

Keywords: *Asymmetric loading;Basement; Diaphragm wall; Finite element method; Retaining structure.*

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I. Introduction

Retaining structures and supported systems for deep excavation in urban areas near of a river, are often subjected to unbalanced lateral load due to asymmetric loading. The various publications and design guides give special guidance on overall stability of retaining structures and strutting systems in such conditions [1, 2]. Case histories on braced excavations under unbalanced/non-symmetrical lateral loading also have been reported by Thasnanipan et al. (1998), De Rezende Lopes (1985) and Kotoda et al. (1990) [3, 4, 5].Yong et al. (1989) showed that therate of lateral wall movement is about 1 to 3 mm/day during excavation and 0.4 to 0.7 mm/day after excavation [6].

For a better understanding of the behaviour of excavations with asymmetric lateral loadings, a case study of multi-propped excavations under unsymmetrical lateral loading in Chao Phraya river formation which is located in Bangkok is presented herein. The analysis of this case study is assessed through direct comparison between field measured data such as inclinometer and strain gauges readings with themodelled lateral wall displacements and strut forces.This case study is for the second building in Thamasart University Project which has a basement excavation of 9.70 m below the ground level supported by braced diaphragm walls along the bank of the Chao Phraya River, Bangkok and adjacent to existing structures. The design and construction aspects of this project have been reported by Thasnanipan et al. (1999) [7].Also, the monitoring of diaphragm wall displacement and associated ground movement have been reported byTansenget al. (2001) [7, 8].

Finite element method (FEM)isused to assess the effects of soil stiffness parameters on the performance of multi-propped excavations under unsymmetrical lateral loading in Chao Phraya river formation using both soil constitutive models;Mohr-Coulomb (MC) and Hardening Soil (HS)and using Plaxissoftware V8.2. A comparative studybetween symmetric and unsymmetrical FEM for the case study to determine the effects of asymmetrical lateral loading on diaphragm wall lateral displacement and struts forces.

II. Site description

Thebuilding site is located along the river and surrounded by existing structures including a historical building as shown in Figure (1). Thefoundations systems of the surrounding existing buildings were piles. The distance between diaphragm walls along the river side and the existing old river wall is about 10.0 m length. It is also situated in the heart of an old established culturally-significant zone.

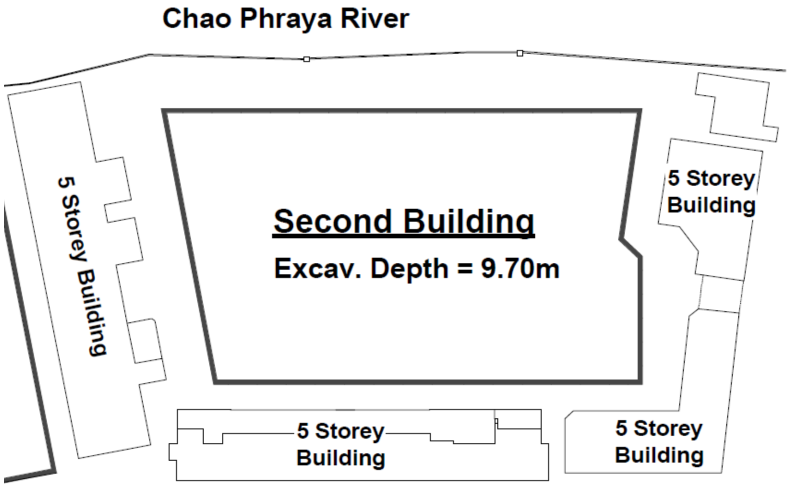


Fig. (1) The layout of building under study.[after Thasnanipan et al., 1999]

At the building site, the river is about 205m wide and 10-12m deep at mid-stream. The riverbed near the river wall is about 2.2-3.0m in depth with a gentle slope. The river water level in dry season is about1.6m below ground level while in the rainy season sometimes rises above ground level.

III. Subsoil conditions

Table no. 1 shows a summary of subsoil properties obtained from the boreholes and field vane shear test data according to Thasnanipan et al. (1999).

Table no. 1: Summary of subsoil properties

Soil type	Layer top in depth (m)	w (%)	γ_s (kN/m^3)	c_u (kPa)	SPT (blow)
Soft Clay	0 – 3.0	35-78	16 – 19	30	
Med. Clay	12.7	30	19	71	
Stiff Clay	14.0	22 – 34	19 – 21	43 – 300	14 – 52
Dense Sand	25.0	14-25	20 – 23	-	35 – 50
Silty Clay	36.5	17 – 21	20 – 23	175 – 240	30 – 45
Dense Sand*	42.0 – 45.0	20 – 26	21	–	>58

* Some 4-5 m thick hard clay seams present at depth 48-52 m

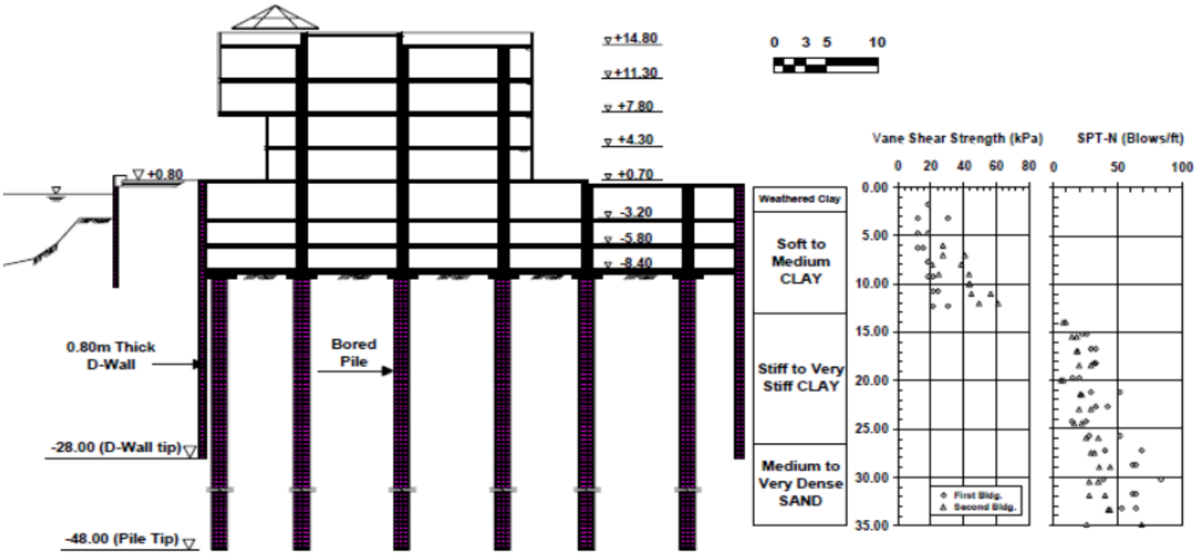


Fig. (2) Basement section and soil profile. [after Thasnanipan et al., 1999]

IV. Description of side support system under study and instrumentation

For all building sides, 800mm thick cast in-situ concrete diaphragm walls (DW) of 28m toe depth with two level temporary bracings were designed for basement excavation. The maximum excavation depth for the building is 9.7m. The 28m deep walls were necessary for overall stability of excavation as they were located on the riverbank. A simple cross-lot bracing system with continuous wale beams was used as shown in Fig. (3). 20m and19m long, steel king posts of H300 x 300 in section were used to support the working platform and bracing system, the temporary bracing system details are summarized inTable no. 2.

Table no. 2: Summary of steel sections for the temporary bracing

Bracing No.	Building BracingLevel	Strut Sections
1	-2.0	1 x WF400 x 400
2	-7.0	2 x WF350 x 350

As construction sites were located in a very sensitive urban area and subjected to unbalanced lateral loading conditions, various types of instrumentation were installed and systematically monitored. Layouts of instrumentations are shown in Fig. (3). 5 levels of vibrating wire strain gauges (VWSG) in pairs were installed in one diaphragm wall panel and 2 sets of earth pressure gauges were installed in struts to observe stress in the diaphragm wall and strut forces respectively.

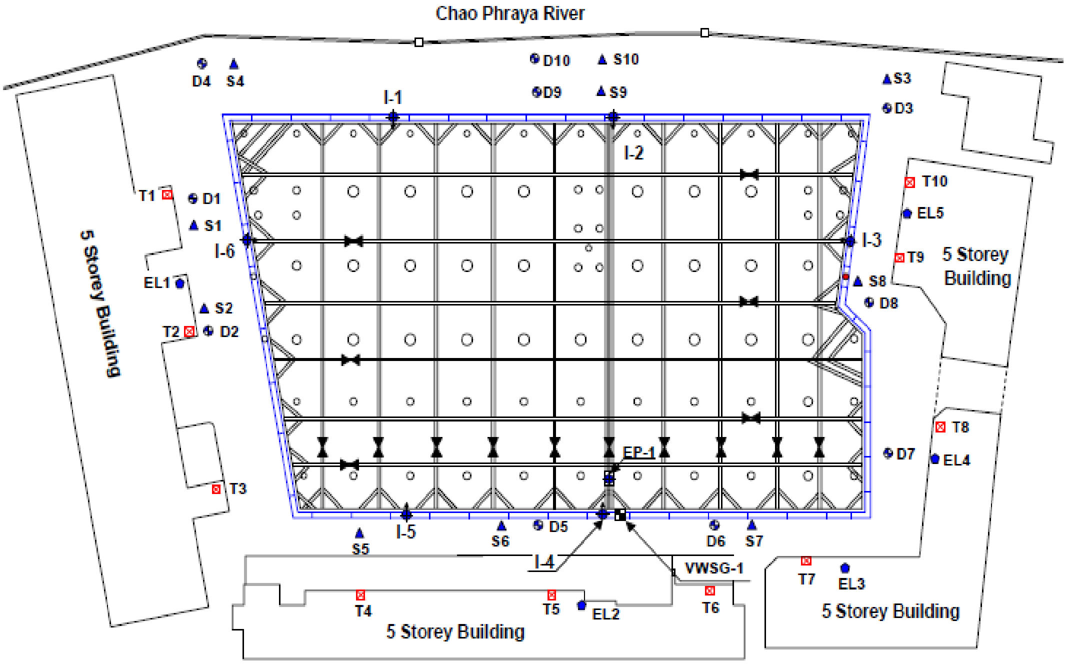


Fig. (3) Layout of temporary bracing and instrumentation.[after Thasnanipan et al., 1999]

V. Excavation work plan

General

Conventional bottom-up method with two levels of temporary bracing was adopted for excavation to construct foundation and basement floors, according to Thasnanipan and Teparaksa et al. (1999).A two-dimensional analysis was carried out using Plaxisfinite element computer program to study the possible behavior of the wall system under unbalanced lateral loading conditions. Such conditions were considered to be resulting from the following:

1. Excavation depth of the earth,
2. A step sloping river bed,
3. Full depth of earth with possible surcharges from the adjacent buildings.

A major concern was that the diaphragm walls alongside the river would be thrust from the opposite walls.These bore a higher lateral load through axial force of struts as excavation progressed in stages. This wall behaviour was indicated by computer modelling Fig.(4). To prevent any adverse wall behaviour alongside the river, the following measures were taken;

1. Using a simple and efficient temporary bracing system,
2. Pre-loading on one end of struts on the opposite walls,

3. Excavating first soil in front of the wall closest to the river at any excavation stage,
4. Frequently monitoring of wall movements,
5. Minimizing construction time.

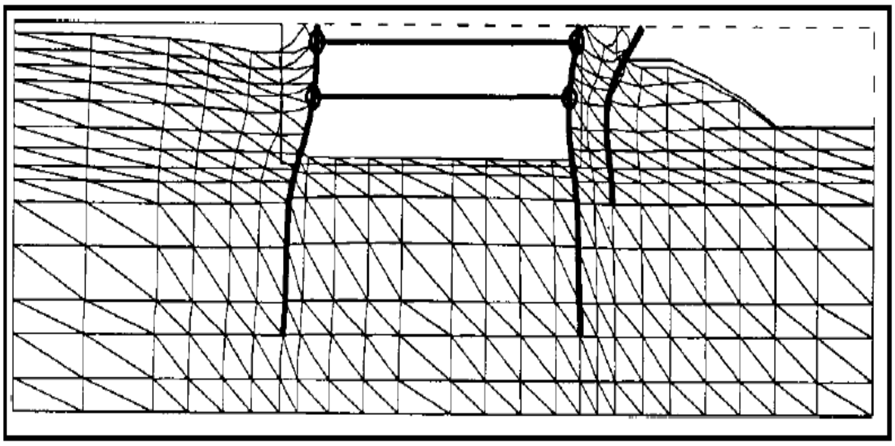


Fig.(4) Behaviour of walls shown by deformed mesh of two-dimensional model. [after Thasnanipan et al., 1999]

Moreover, observational constructions approach (Ikuta et al. 1994), using the "most probable" conditions and parameters in the design with contingency plan for "most unfavourable" conditions was employed. Firstly, a monitoring plan was established before excavation. Secondly the instrumentation monitoring data were used to trigger the contingency plan. Generally, predicted wall movements were set as primary trigger values for the contingency plan.

Excavation work sequence

The excavation work sequence in site passes through the following steps respectively:

1. Construction of 0.8m thick. D-walls.
2. Excavation to level (-2.50), at day 67.
3. Install first strut at level (-2.00), at day 65.
4. Excavation to level (-7.50), at day 133.
5. Install second strut at level (-7.00), at day 110.
6. Excavation to final level (-9.70), at day 155.

VI. Instrumentation results

General

Construction activities and the corresponding results of instrumentation monitoring with construction time are presented in Fig.(5). This figure indicates a good relationship between construction activities on one hand and responses of the walls, existing buildings and ground on the other hand. It can be observedthat significant changes in these responsesgenerally occurred during the initial excavation stage.

During the period of delay, monitoring of instrumentation was frequently carried out to compare the monitoring data and the trigger values for planning a contingency plan against possible risks to adjacent structures from unsupported excavations to 2.50 m depth.

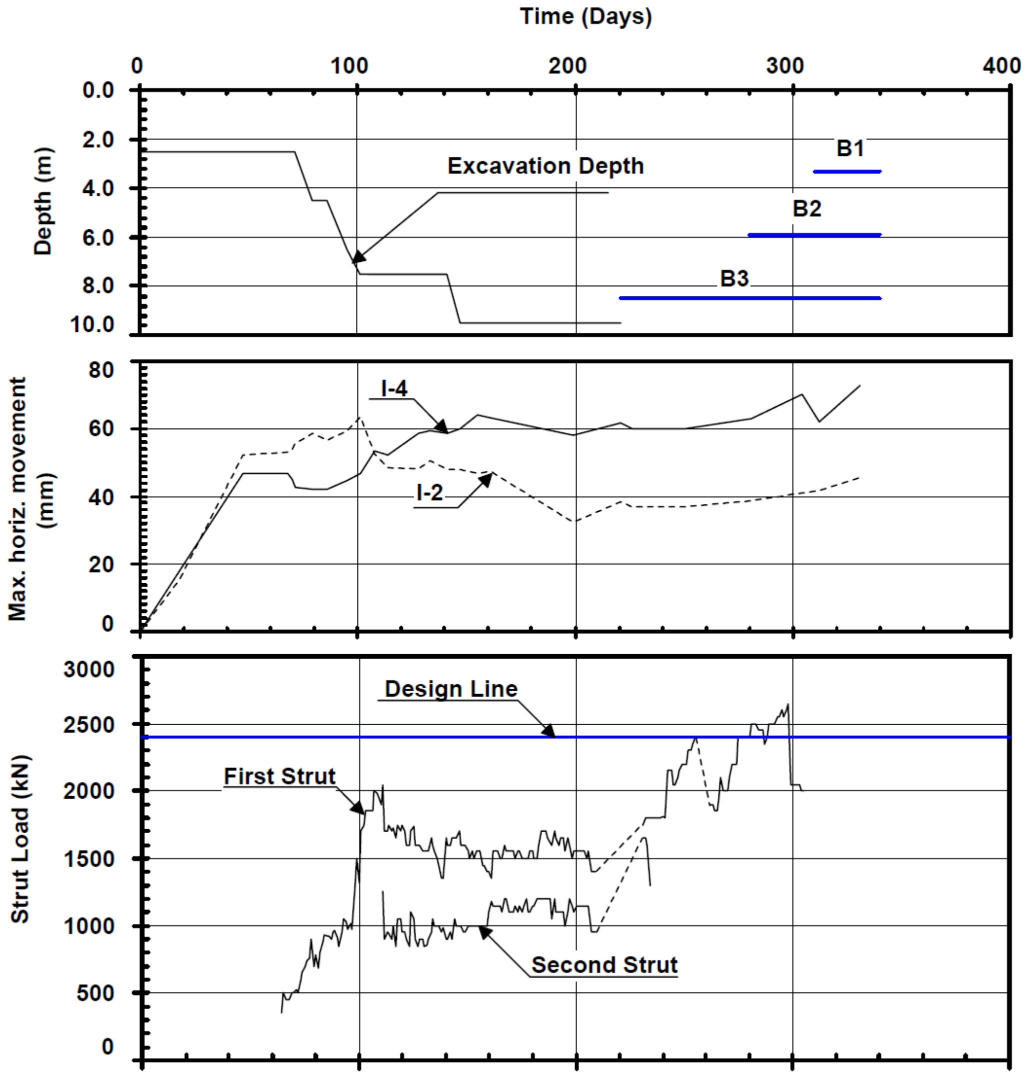


Fig.(5) Instrumentation results with construction time Inclinometers. [after Thasnanipan et al., 1999]

Inclinometer monitoring

The wall movements weremonitored weekly, sometimes every 2-3 days whennecessary. The lateral wall movement had reached a maximum rate of 6.5mm/day.

Regarding the unbalanced lateral loading condition, monitoring results from inclinometers I-2 and I-4 suggested that the wall alongside the river had been pushed against the retaining soil by the opposite wall Fig.(6). All inclinometer readings indicated that the walls were in fixed-end condition with fixity at depths of about 20.00m.

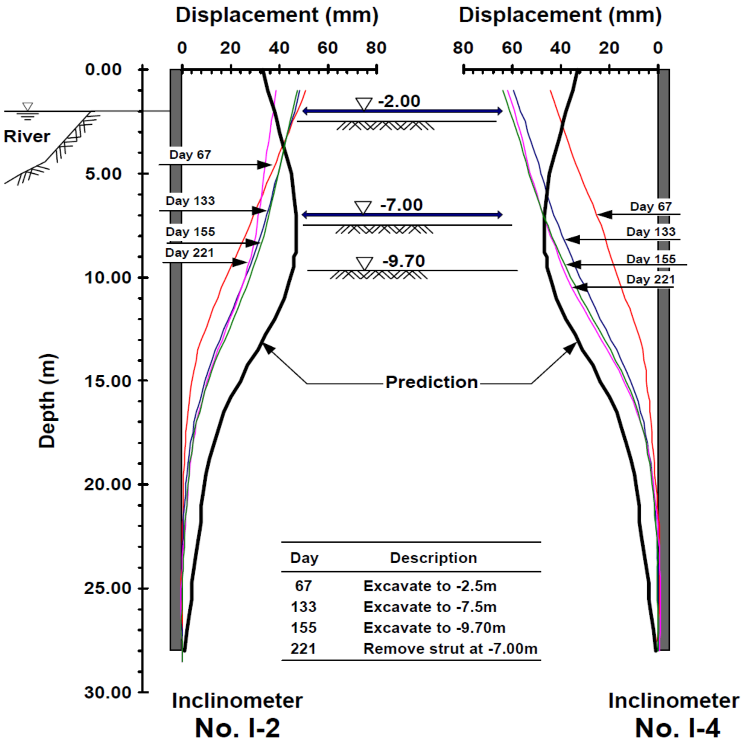


Fig.(6) Lateral wall movements. [after Thasnanipan et al., 1999]

Maximum wall movements after installation of bracing ranged from 0.27% to 0.83%. These were also within the range (about 0.1% to 1.2% of excavation depth) of wall movements in other projects completed in Bangkok area.

Strut pressure gauges

The readings from the pressure gauges installed on struts indicated that the bracing system used was adequate. According to Thasnanipan et al. (1999), the measured strut forces are presented in Table no. 3.

Table no. 3: Predicted, allowed and measured strut forces.[after Thasnanipan et al., 1999]

Item	First level (kN/m)	Second level (kN/m)
Predicted by WALLAP	354.5	307.3
Allowed	279.4	332.1
Measured	331.3	206.2

VII. Finite Element Analysis

General

The main aim of these numerical runs is to study the effects of the soil constitutive models parameters on behaviour of unbalanced loaded braced diaphragm wall in Chao river formation. In this studya 2-D finite element analysis model for the case under study was carried out using Plaxis8.2 finite element computer program using MC constitutive soil model. The finite element analysis of such retaining system requires a set of data to be identified. The data required for the analysis includes soil properties, soil stratigraphy, wall properties, excavation width and depth, strut propertiesand construction stages. Such data was discussed in following items.

Soil properties for constitutive soil models (MC and HS)

The main required soil parameters for analysis are soil shear strength and soil stiffness parameters.The shear strength parameters were taken from the field tests results data mentioned in item 1.3 andTable no. 1-1).To reach more indicative soil stiffness parameters for such soils, some related publicationswererevised.Finally,it was found thatThasnanipanet al. (1999)presented case histories and back analyses of diaphragm walls for deep based excavations in Bangkok subsoil, one of the studied case histories in this paper was Thamasart University Project (the first building).Thisback-analysis study was carried out using 2D-FEM program “Plaxis” specially using MC soil model. Thestudy results showthat the soil stiffness parameters in terms of Eu/Cu = 500 and 2000 for soft and stiff Bangkok clay, respectively is recommended.

Based on the above,the soil stiffness parameters were estimated for both soil models (MC and HS). The subsoil layers and soil properties are summarized inTable no. 4.

Table no. 4: Subsoil layers and soil properties for both soil models

Parameters	**Soft clay**		**Med. clay**		**Stiff clay**		**Dense sand**	
Layer top level	0.0		-12.7		-14.0	-35.0	-25.0	-42.0
Layer thick. (m)	12.7		1.3		11.0	7.0	10.0	18.0
Soil model	MC	HS	MC	HS	MC	HS	MC	HS
$\gamma_{sat}/\gamma_{sub}$ (kN/m^3)	18	18	19	19	20	20	20	20
K_o	0.593	0.593	0.546	0.546	0.455	0.455	0.357	0.357
ϕ`	24	24	27	27	33	33	40	40
C` (kPa)	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0
R_{inter}	65%	65%	65%	65%	65%	65%	70%	70%
E` (kPa)	15000	-	30500	-	74000	-	75000	-
$E_{increment}$ (kPa/m)	-	-	-	-	40190	-	10000	-
ν	0.35	-	0.35	-	0.30	-	0.3	-
E_{50}^{ref} (kPa)	-	35960	-	47220	-	356200	-	123800
E_{oed}^{ref} (kPa)	-	34050	-	41680	-	227100	-	99970
E_{ur}^{ref} (kPa)	-	179800	-	236100	-	1781000	-	371300
ν_{ur}	-	0.2	-	0.2	-	0.2	-	0.2
m	-	1.0		1.0	-	1.0	-	0.5

Wall Depth and properties

D-walls are 800 mm thick cast in-situ reinforced concrete diaphragm walls extending to a depth of 28.0 mfor purpose of analysis the D-wallsweresimulated as plate elementwith basic properties mentioned inTable no. 5.

Table no. 5: Basic properties of 800 mm thick cast in-situ concreteD-wall

Wall thickness (d) m	Wall depth m	Normal Stiffness (EA) kPa/m`	Bending stiffness (EI) kPa/m`
0.8	28.0	$1.60\text{x}10^7$	$8.53\text{x}10^5$

Where,E (Elastic Modulus) for concrete = $2.0\text{x}10^7$kPa

Strut properties

D-walls were braced with temporary bracing at 2 different levels;the first strut is (WF 400x400) steel beams at level (-2.00), while the second the strut is 2x (WF 350x350) steel beams at level (-7.00). The basic properties of the struts were mentioned inTable no. 6.

Table no. 6: Basic properties of the struts

Bracing No.	Bracing Level	Strut Sections	Section area (A) m^2	Normal Stiffness (EA) kN
1	-2.00	1 x WF400 x 400	$218.7\text{x}10^{-4}$	$4.374\ \text{x}10^6$
2	-7.00	2 x WF350 x 350	$2\text{x}173.9\text{x}10^{-4}$	$6.956\ \text{x}10^6$

Where,E (Elastic Modulus) for steel = $2.0\text{x}10^8$kPa and $L_{Spacing}$ (spacing between struts) = 8.0 m.

Model Geometry

The model dimensions had been chosen with respect to the available geotechnical data (borehole depth 60.0m).For purpose of comparing model results with field data, the model section chosen for analysis was the section between the inclinometers I-2 and I-4. The distance between the excavation sides D-walls at this section is about 50.m, and the distance between the wall at the river side and the river wall is about 8.0m, the berm width in front of river wall is about 3.0m, the berm level is about (-3.00), while the river bed level is about (-12.00) with gentle slope. The ground water level as well as the water level in river is considered to be (-1.00),Fig.(7) shows the model geometry and the subsoil layers condition.

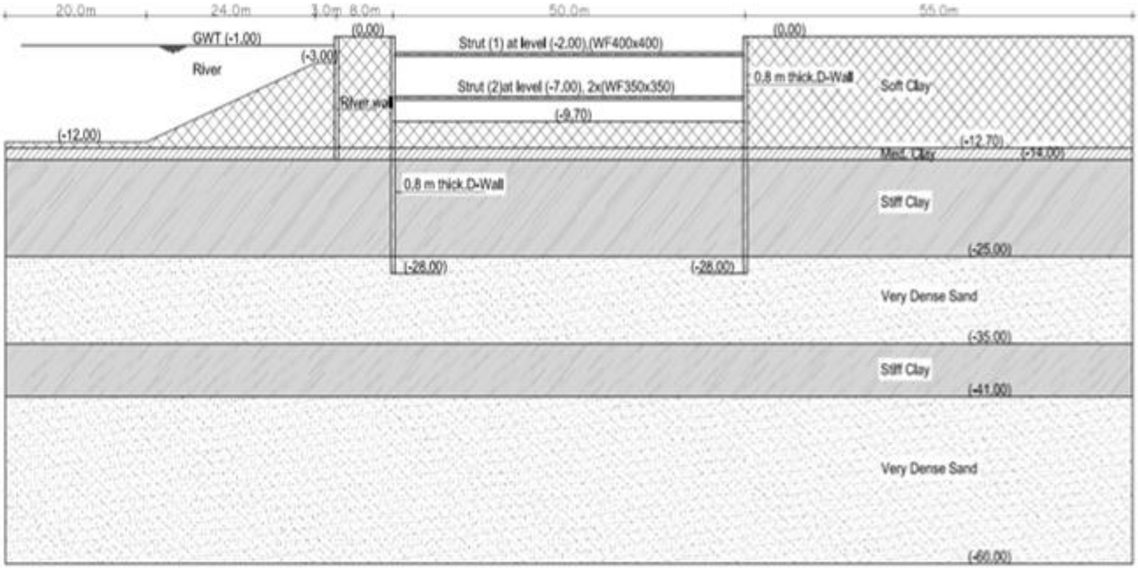


Fig. (7) Model geometry and the subsoil layers condition

Calculation phases

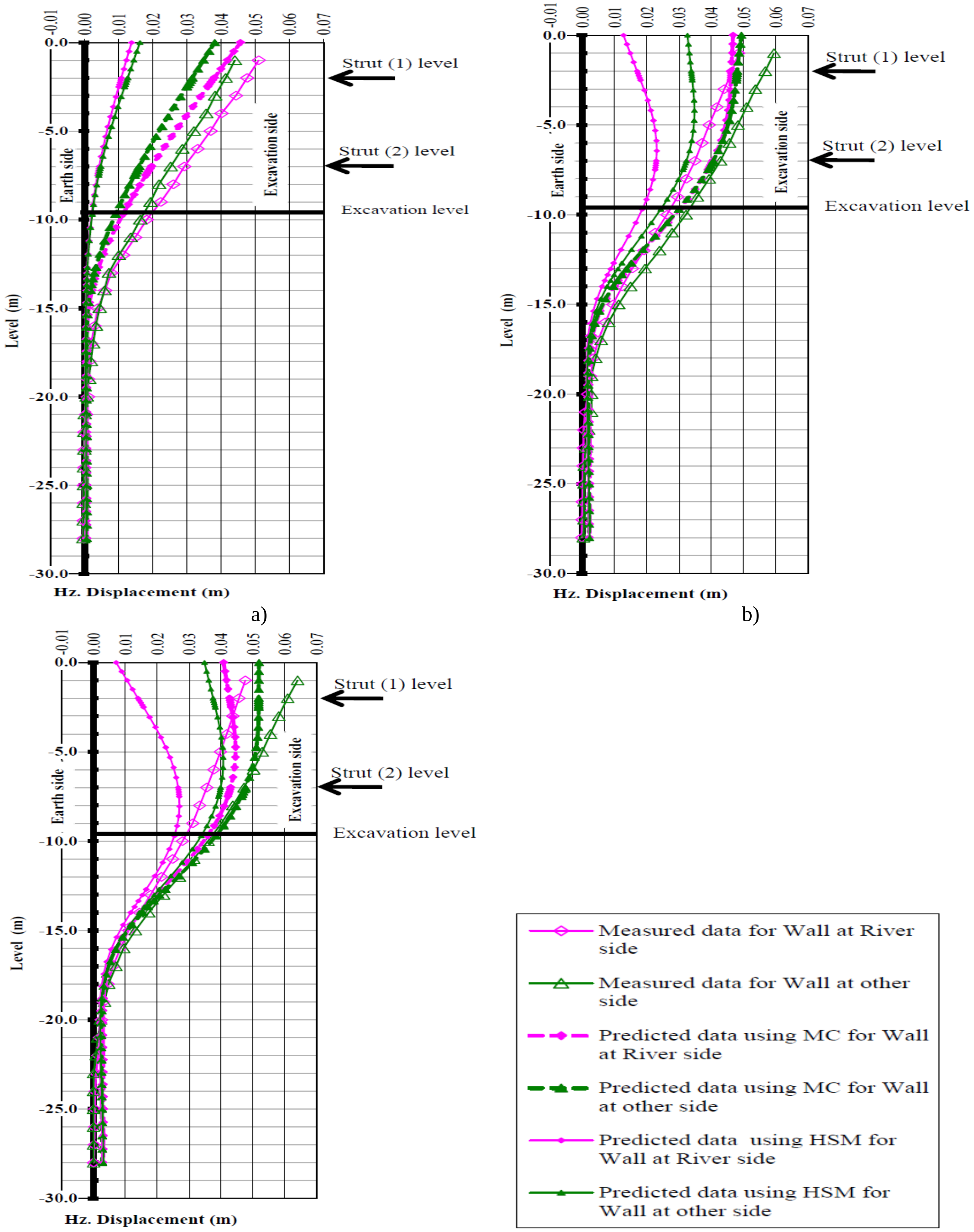
The following calculation phases in model analysis are simulating the construction steps during system construction.

1- Initial condition
2- Installing D-walls
3- Excavation to level (-2.50)
4- Install first strut at level (-2.00)
5- Excavation to level (-7.50)
6- Install second strut at level (-7.00)
7- Excavation to final level (-9.70)

VIII. Results of the analysis

Horizontal displacement

The horizontal displacements obtained from both MC and HS modelswere plotted as well as the measured data against the diaphragm wall level as shown in Fig. (8).



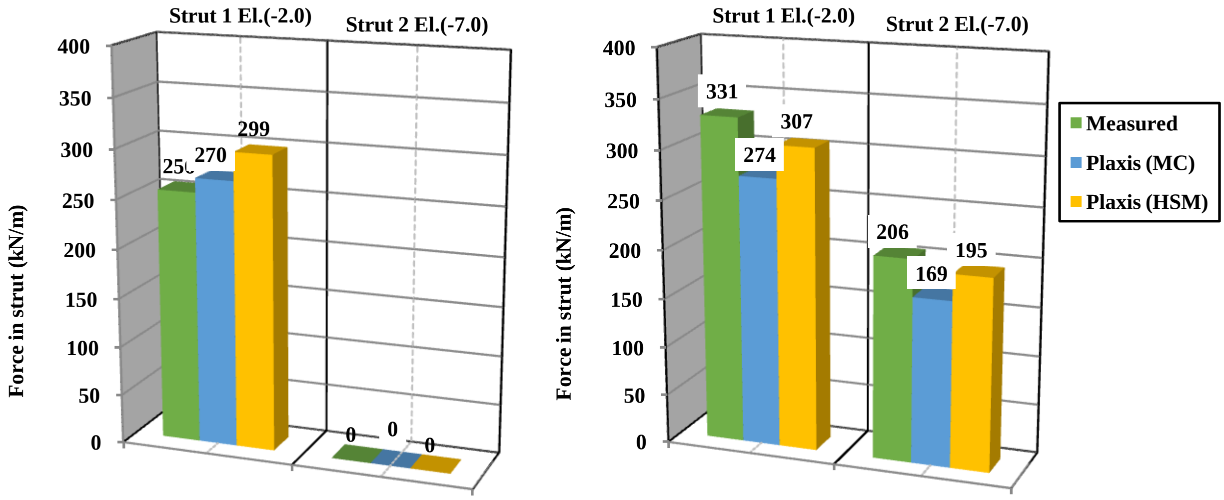
a) b)

c) d)

Fig. (8) The measured and predicted horizontal displacement for both side walls at: a) day 67; b) day 133; c) day 155; d) legend

Strut force

The struts forces obtained from both HS and MC model had been plotted with measured field data for both struts at level (-2.00) and (-7.00) as shown in Fig. (9).



a) b)

Fig. (9) The measured and predicted struts forces for both struts at levels: a) at day 133; b) at day 155

Discussion of results

As shown in Fig.(8), a clear effect on walls horizontal displacements had appeared due to the unbalanced loading condition resulting from the existence of river slopes in one side of the excavation. This effect was appearedclear especially along the upper 12.0m of the walls.

Since, the recommended values for stiffness parameters in terms of Eu/Cu = 500 and 2000 for soft and stiff Bangkok clays respectively were taken from a previous back analysis study [7]which was carried out using MC soil model.So, it was expected that the MC results will be more near from the field measured data.The abovementioned figures confirmed that the MC model results were matching with field measured data more than those extracted from HS model.So comparative study between symmetric and unsymmetrical FEM's for the case study will done using MC model only.

IX. Comparative study between symmetric and unsymmetrical FEM's

Model Geometry

The model is assumed to be symmetrical about the centreline of the excavation and only half of the excavation is modelled. The data required for the analysis includes soil properties, soil stratigraphy, wall properties, excavation width, strut properties, depth of the excavation and construction stages are considered as mentioned in item VII.Fig. 10) shows the model geometry and the subsoil layers condition.

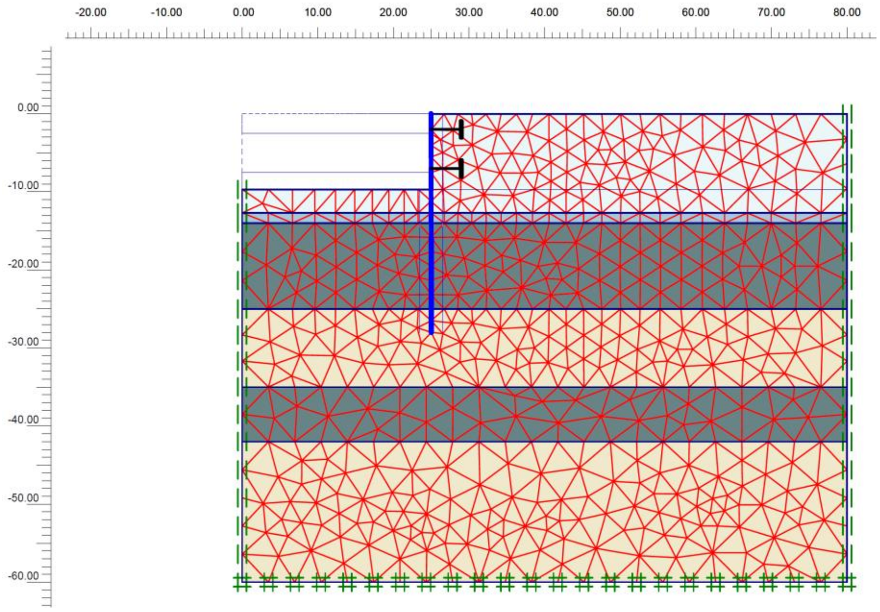
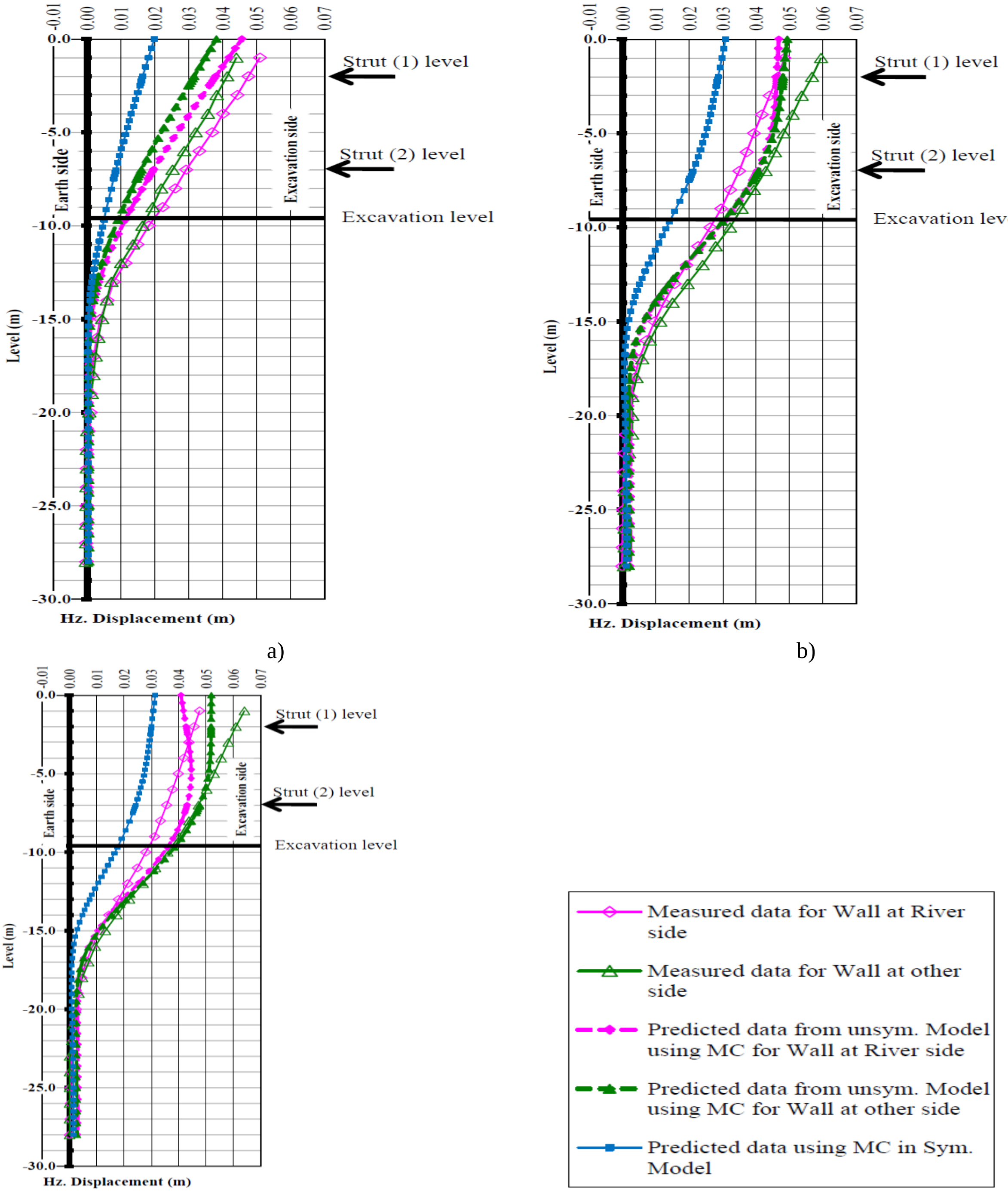


Fig. (10) Symmetric model geometry from Plaxis

Results of the analysis

The horizontal displacement obtained from both symmetric and asymmetric models using MC models were plotted with measured data as shown in Fig. (11).In addition, the struts forces obtained from both symmetric and asymmetric models using MC models had been plotted with measured field data for both struts at level (-2.00) and (-7.00) as shown in Fig. (12).

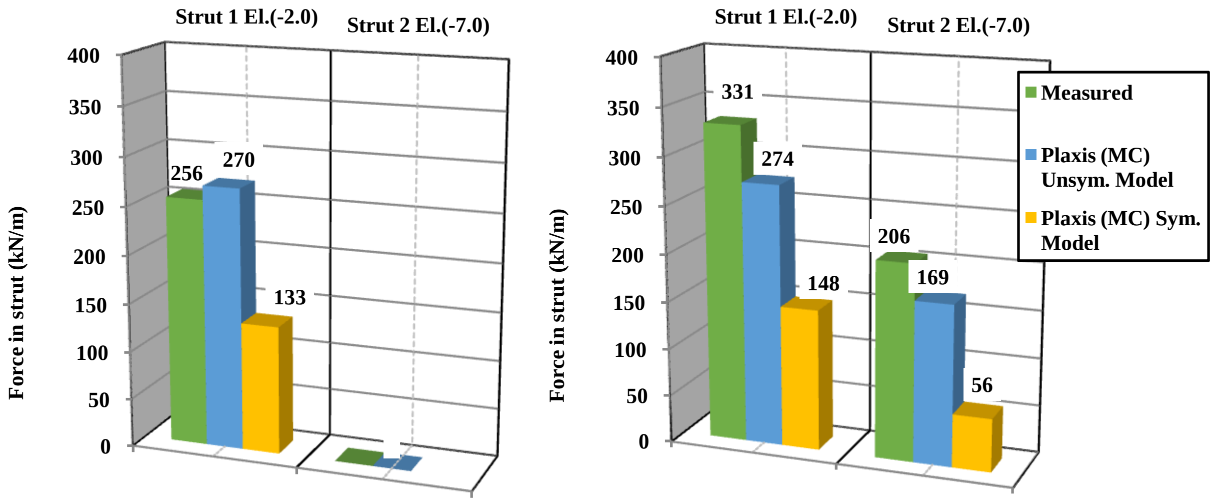
From figures (11) and (12), it can be obvious that the predicted values of horizontal displacement of the diaphragm wallusing MC model(for stiffness parameters in terms of Eu/Cu = 500 for soft Bangkok clay and Eu/Cu = 2000 for stiff Bangkok clay) were more near tothe field measured values.Also, the strut forces values obtained from analysis using asymmetric model for both walls are clearly more near from the field measured data than that obtained from analysis using asymmetric model.



a) b)

c) d)

Fig. (11) The measured horizontal displacements and predicted ones using MC for both symmetric and asymmetric modelsat: a) day 67; b) day 133; c) day 155; d) legend



a) b)

Fig. (12) The measured forces in strutsand predicted ones using MC for both symmetric and asymmetric models: a) at day 133; b) at day 155

X. Conclusions

This paper presents a comparison between values of diaphragm walls deflection and forces in struts at levels (-2.00) and (-7.00) of the second building in Thamasart University Project during constructionby FEM analysis and by field measurement. Two constitutive soil modelswere considered: Mohr-Coulomb (MC) and Hardening Soil (HS) modelsto simulateall the construction sequences. The main conclusions can be summarized as:

1- The unbalanced loading condition resulting from the existence of river slopes in one side of the excavation cause a different horizontal displacements values for both diaphragm walls. In other words, the horizontal displacements values for the wall nearby the existence of river slopes is less than horizontal displacements values for the other side wall.

2- The predicted values of horizontal displacement of the diaphragm wallusing MC model were more near tothe field measured values than those extracted from HS model.

3- The horizontal displacements values obtained from analysis using asymmetric model for both walls are clearly more near from the field measured data than that obtained from analysis using asymmetric model. Also, the strut forces values obtained from analysis using asymmetric model for both walls are clearly more near from the field measured data than that obtained from analysis using asymmetric model.

References

[1]. Williams, B. P and Waite D. (1993). The design and construction of sheet-piled cofferdams. CIRIA Special Publication 98, Thomas Telford Publications.

[2]. Padfield, C. J. and Mair, R. J. (1991). Design of retaining walls embedded in stiff clay. CIRIA Report 106. Construction Industry research and Information Association. Lon-don, UK.

[3]. Thasnanipan, N., Maung A. W., Tanseng P. and Wei S. H. (1998). Performance of a braced excavation in Bangkok clay, diaphragm wall subject to unbalanced loading conditions. Thirteenth Southeast Asian Geotechnical Conference, 16-20 November, 1998, Taipei, Taiwan. Pp. 655-660.

[4]. De Rezende Lopes, F. (1985). The problem of asymmetricsurcharges in strutted excavations. Ground Engineering, vol. 18, no.2, pp 31-35.

[5]. Kotoda, K., Kazama, S., Ogawa, H. and Kato, K. (1990). Behavior of earth retaining structure for excavation subjected to non-symmetrical lateral loading. Tenth Southeast Asian Geotechnical Conference, 16-20 April 1990, Taipei, Tai-wan. pp. 539-544.

[6]. Yong, KY., Lee, F.H., Parnploy, U., and Lee, S.L. 1989. Elasto-plastic consolidation analysis for strutted excavation in clay. Computers and Geotechnics, 8(4), 311-328.

[7]. Thasnanipan N., Maung A. W., Tanseng P. and Teparaksa W., “Behavior and Performance of Diaphragm Walls under Unbalanced Lateral Loading along the Chao Phraya River”, Proceeding of the 5th International Symposium on Field Measurements in Geomechanics, Singapore, 1999, pp. 273-278.

[8]. Tanseng P., Aye Z.Z. and Submaneewong C.,” Monitoring of diaphragm wall displacement and associated ground movement, brace excavation adjacent to historical building at the bank of Chao Phraya River”, Proceeding of the 7thNational Convention onCivil Engineering, Philipine, 2001, pp. 53-60.