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Behavior of Deep Excavations Using Sheet Pile Bracing System in Soft Bangkok Clay

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SYNOPSIS The sheet pile bracing system is the most wellknown for excavation work in Bangkok soft marine clay. The sheet pile wall which is defined as flexible wall will show a large significant of lateral deformation and ground surface settlement if the excavation system is carried out without a good quality control. The sheet pile bracing system with fully effective preloading strut system was designed for basedment excavation of 11.3 m. deep of Bai Yok Tower II. The results indicate that berm width can reduce the maximum sheet pile wall deflection only at the first three stages of excavation. The fully effective preloading strut system tend to show the lower measured wall deflection ratio against basal heave than those proposed by Mana & Clough (1981). The prediction of maximum wall deflection by simplified method proposed by Wong & Brom (1989) agree well with the field measurement only at the final stage of excavation.

INTRODUCTION

The Construction of high-rise and deep basement is rapidly increasing in recent year in Bangkok city, capital of Thailand. Basement floor is realy necessary due to landlimited as well as Bangkok Methopolitant Authority regulation for car park. As wellknown that Bangkok subsoils consists of very thick soft marine clay with undrained shear strength in the order of less than 1.5 ton/m^2. The typical soil profile, consists of about 16 m. soft to medium grey clay then followed by stiff to very stiff silty clay to about 23 m. and reach first silty sand layer. Sheet pile bracing system (Flexible retaining structure) is commonly used for general basement excavation of about 9 m. deep. This depth limitation is due to the induce of large lateral deformation of sheet pile and will lead to an induce the damage to the nearby structures (Teparaksa, 1991 & 1992). For deeper excavation, the rigid retaining structures such as diaphragm wall, secant pile wall and Berlin wall are adopted.

The Bai Yok II tower is the highest highrise building under construction in Bangkok city. It is the 89 storeys building and consists of 11.3 m. deep excavation for construction of basement and mat foundation. The flexible wall, sheet pile bracing system with fully effective preloading strut system, was firstly introduced by the author for excavation in very soft Bangkok clay.
This underground construction was finished by end of February, 1992.

This paper evaluate the influence of numbers of factors effected to the lateral displacement and surface settlement and during the excavations of Bir Yok II tower in soft Bangkok clay. The simple prediction of behaviour of sheet pile bracing system for this deep excavation is also compared with field performance.

SUBSOILS CONDITIONS

Bai Yok II Tower, where is seem to be the highest tower in Bangkok city, is located in central of Bangkok. The Bangkok clay is known that very soft and thick which subsoils consists of about 13.5 m. thick soft to medium marine clay and its undrained shear strength is in the order of 0.6 to 2 t/m^2. The alluvial stiff silty clay is found below soft clay to about 27 m. deep then followed by thin first clayey sand layer to about 30 m. deep. The typical soil conditions including undrained shear strength and SPT N-values is presented in Figure 1.

BRACED EXCAVATION SYSTEM AND GEOTECHNICAL INSTRUMENTATION

The research site is located at the construction area of Bai Yok II tower where the excavation area was about 50x90 m. The excavation sequence was arranged into 2 zones as zone 1 and zone 2 where the excavation depth was about 9.5 and 11.3 m., respectively. This excavation sequence was planned according to the supply of sheet piles which is shortage in Bangkok during construction.

Zone 1 excavation is the podium of 19 storeys consisted of 2.5 m. thick mat foundation, while zone 2 excavation is the highrise zone of 89 storeys building with 5.0 m. thick of mat foundation. Construction joint of about 1.5 m. wide was provided between podium and highrise building where the inner sheet pile was also installed along this boundary during excavation. Figure 2 shows the excavation plan including sheeet pile, strut and instrumentations. The excavation area is surrounded with commercial buildings where the nearest building is the 4 storeys building located about 70 cm. behide the sheet pile wall which is at the conner of zone 2 excavation area as shown in Figure 2.

Four steps of bracing was designed for this construction as shown in Figure 3. For zone 1 excavation (9.5 m. deep) only three strut bracings were used while four strut levels were applied for zone 2 excavation (11.3 m. deep). Sheet pile wall type JSP 4 (JIS-Standard) of 18 m. long with stiffness (EI) of 8106 ton/sq. m. per linear meter was designed for excavation work. The section and properties of sheet pile was presented in Figure 4. The strut and wale of H 300x300x94 kg/m section was used for the first bracing layer, while H 350x350x137 kg/m was for the 2nd, 3rd and 4th layer. King post of 21 m. long of H 350x350x137 kg/m section was arranged for spacing of 4.5 to 5.50 m. interval. The king post was designed to carry the excavation machine and truck from platform. The properties of H-beam for strut, wale and kingpost is summarized in Table 1.

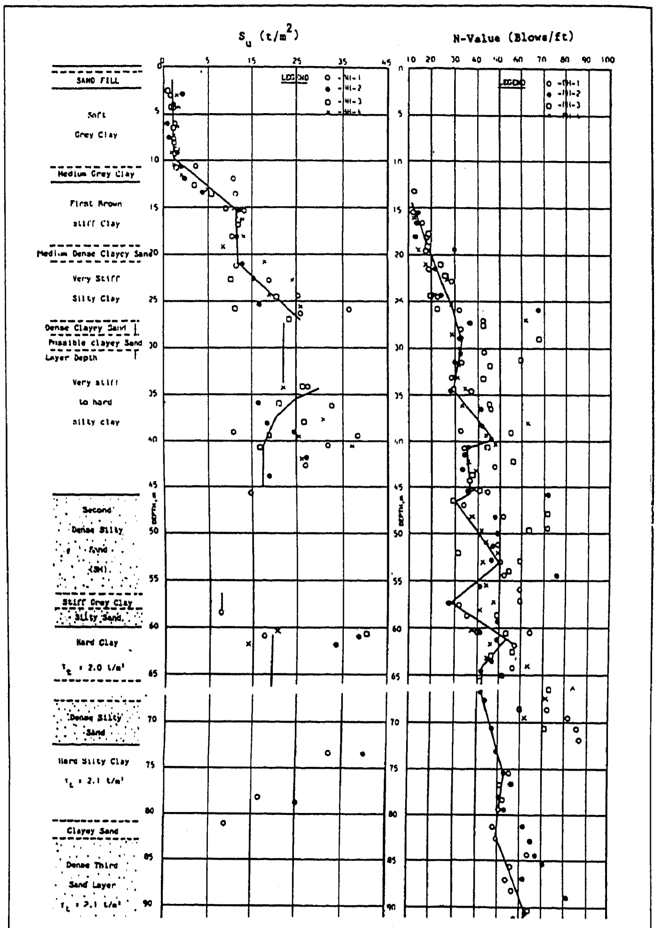


Figure 1 Typical soil properties against depth

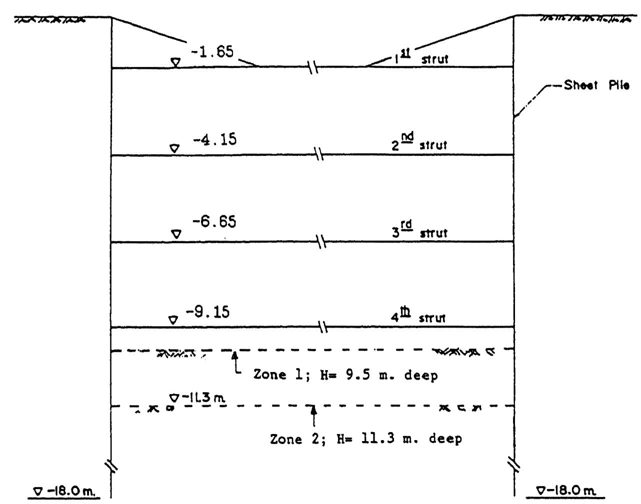


Figure 3 Detail of excavation system

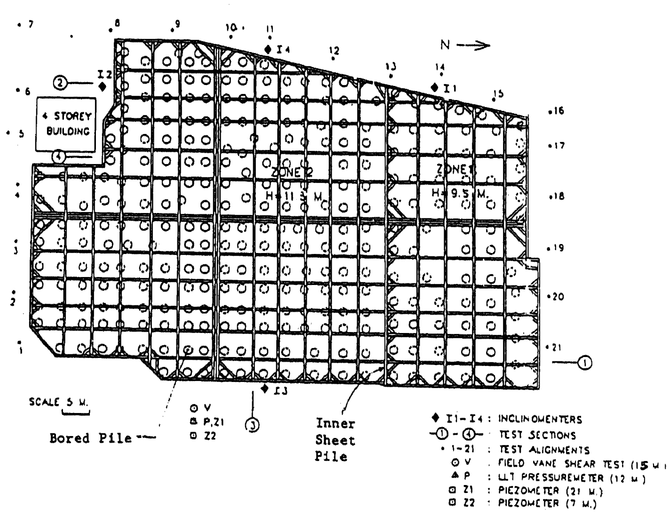
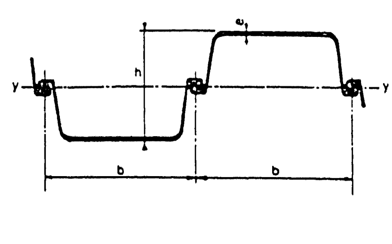


Figure 2 Plan of excavation area and location of geotechnical instruments.

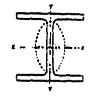


Profile	Width b mm	Height h mm	Back thickn. e mm	Sectional area cm²/m of wall	Mass kg/m of s. pile	Mass kg/m² of wall	Section Modulus cm³ per s. pile	Section Modulus cm³/m of wall 1)	Moment of inertia cm⁴ per s. pile	Moment of inertia cm⁴/m of wall
JSP 4*	400	340	15.5	242	76.1	190	362	2270	4670	38600

1) considered neutral axe: y-y

Figure 4 Section and properties of sheet pile type JSP4.

Table 1 Section and properties of H-Beam for strut, Wale and Kingpost



METRIC SERIES.

Section Index	Weight	Depth of Section (A)	Flange Width (B)	Thickness Web (t_1)	Thickness Flange (t_2)	Corner Radius (r)	Sectional Area	Moment of Inertia Jx	Moment of Inertia Jy	Radius of Gyration ix	Radius of Gyration iy	Modulus of Section Zx	Modulus of Section Zy
mm	kg/m	mm	mm	mm	mm	mm	cm^2	cm^4	cm^4	cm	cm	cm^3	cm^3
	106.0	304	301	11	17	18	134.80	23,400	7,730	13.20	7.57	1,540	514
	106.0	300	305	15	15	18	134.80	21,500	7,100	12.60	7.26	1,440	466
300×300	94.0	300	300	10	15	18	119.80	20,400	6,750	13.10	7.51	1,360	450
	87.0	298	299	9	14	18	110.80	18,800	6,240	13.00	7.51	1,270	417
	84.5	294	302	12	12	18	107.70	16,900	5,520	12.50	7.16	1,150	365
	159.0	356	352	14	22	20	202.00	47,600	16,000	15.30	8.90	2,670	909
	156.0	350	357	19	19	20	198.40	42,800	14,400	14.70	8.53	2,450	809
	137.0	350	350	12	19	20	173.90	40,300	13,600	15.20	8.84	2,300	776
350×350	131.0	344	354	16	16	20	166.60	35,300	11,800	14.60	8.43	2,050	669
	115.0	344	348	10	16	20	146.00	33,300	11,200	15.10	8.78	1,940	646
	106.0	338	351	13	13	20	135.30	28,200	9,380	14.40	8.33	1,670	534

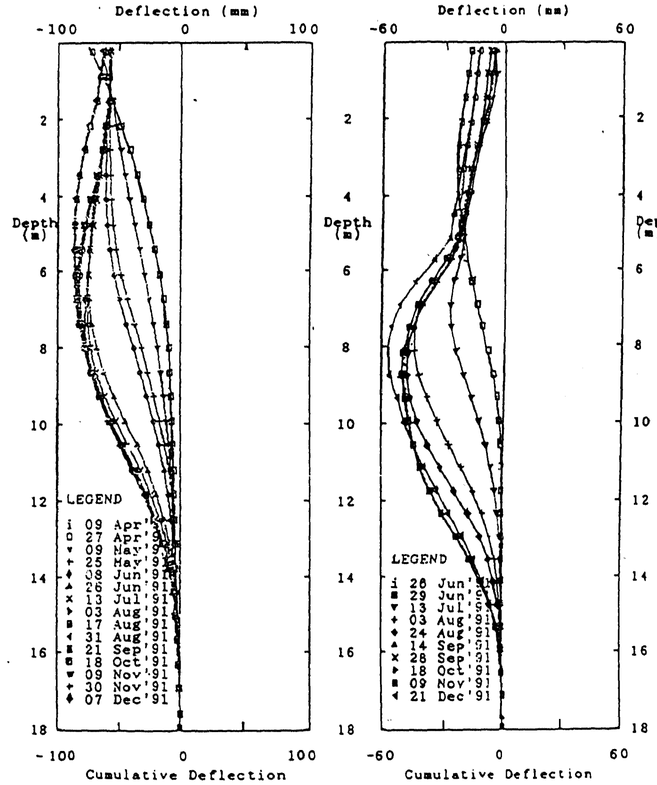
Preloading of strut or prestressing of strut was also adopted for excavation work. Preloading by two hydraulic jacks for one strut was applied immediately after completion of each strut installation. Preloading was applied at both end of strut at the same time with the same order of loading step. Pressure gauge of hydraulic jack and lateral movement of sheet pile was measured in the order of 0.1 mm. of movement during loading. The preloading in each strut of all layers was designed at 70% of the apparent pressure diagram proposed by Terzaghi & Peck (1967) by assuming of 6 ton/m^2 of uniform surcharge load on the excavation surface behind the sheet pile.

The field vane shear test and pressuremeter test were carried out before excavation. The instrumentation including 4-Inclinometers, 2-piezometers and 21-surface settlement points were installed before excavation. The plan of instrumental installation was shown in Figure 2. The inclinometers were installed fixed to the sheet pile with steel casing. After driving sheet pile fixed with steel casing, inclinometer case was installed and filled with cement bentonite.

BEHAVIOUR OF DEEP EXCAVATION USING SHEET PILE BRACING SYSTEM

BEHAVIOUR OF SHEET PILE WALL DEFLECTION

The measurement of wall deflection during the excavation was recorded from the inclinometer I_1, I_2, I_3 and I_4. The inclinometer I_1 was measured at zone 1 excavation (9.50 m. deep), and I_2, I_3 and I_4 were at zone 2 excavation (11.30 m. deep). The first step of excavation was free cantileverexcavation about 2.3 m. deep before bracing strut without provision of berm beside of the sheet pile wall. The wall movement recorded from I_1 inclinometer was about 30 mm. which was rather high as shown in Figure 5(a). The depth of cantilever excavation is rather close to the critical depth (H_c) proposed by Peck (1969) and Clough & Davidson (1979) that the exessive soil movement behide sheet pile wall will be induced. At I_1 inclinometer, the truck traffic for earth hauling was allowed behide the sheet pile wall, therefore, the exessive wall movement was induced. However, at I_4 inclinometer as shown in Figure 5(b), the wall movement was in the order of 24 mm. for first stage of 2.3 m. deep free cantilever excavation. This small deflection is due to the control of trucked traffic for earth hauling by using platform.



(a) I_1- inclinometer (b) I_4- inclinometer

Figure 5 Lateral wall deflection of sheet pile recorded from inclinometer at various stage of excavation

The Lateral wall deflection shows a inward burging shape to excavation side (Figure 5), however, the wall deflection was forced back due to the applied preloading in the strut. The maximum lateral wall movement was induced at about 9 m. deep for final excavation of 11.3 m. deep or at elevation of about 80% of the final excavation depth as shown in Figure 5. The mode of sheet pile wall deflection was in the pattern of wall rotation about the bottom or fixed end type.

RELATIONSHIP BETWEEN MAXIMUM LATERAL WALL MOVEMENTS AND POTENTIAL FOR BASAL HEAVE

The factor of safety against the basal heave was calculated based on the method proposed by Mana & Clough (1981). The factor of safety against basal heave for the intermediate stage of excavation (at 4.5, 7.0, 9.5 and 11.30 m. deep) was summarized in Table 2. The maximum lateral wall deflection for first stage of excavation or cantilever stage was not included in this table. The ratio of maximum lateral wall movement to the excavation depth was summarized in final column. Figure 6 shows the relation of the ratio between maximum lateral wall movement to excavation depth and factor of safety against basal heave. It can be seen that the measurement was within or below the boundary proposed by Mana & Clough (1981). The lower measurement might be due to the effect of 70%

stage of preloading in the strut, which is higher than those proposed by Mana & Clough (1981).

RELATIONSHIP BETWEEN MAXIMUM SURFACE SETTLEMENT AND MAXIMUM LATERAL WALL MOVEMENTS

The maximum surface settlement was measured from 21 number of serface settlement plates which were installed according to the method recommended by Dunnicliff and Green (1988). The measurements were recorded for the case of truck traffic hauling on the ground surface behind the sheet pile wall and for the case of providing platform for truck earth hauling. Figure 7 shows the relationship between maximum surface settlement behide the sheet pile ($\delta_{v\ max}$) and maximum lateral sheet pile wall deflection both for traffic area and non traffic area. It can be seen that the effect of traffic behind the sheet pile wall shows significant in inducing lateral wall movement and surface settlement. The ratio of maximum vertical surface settlement and maximum lateral wall movement is in the order of 0.8-1.6 and 1.9-2.1 for non traffic area and traffic area, respectively.

EFFECT OF BERM WIDTH TO MAXIMUM LATERAL WALL MOVEMENT

The berm width next to the sheet pile inside of the excavation area was provided during bracing of the strut at the middle portion of the excavation area. Period of struting at the middle zone of excavation area is in the order of 7-20 days. After completing of middle strut installation, the berm was removed and the strut was welded from the middle part to the sheet pile wall. Table 3 summarizes the berm width, working period and the measurement of maximum horizontal wall movement ($\delta_{H\ max}$).

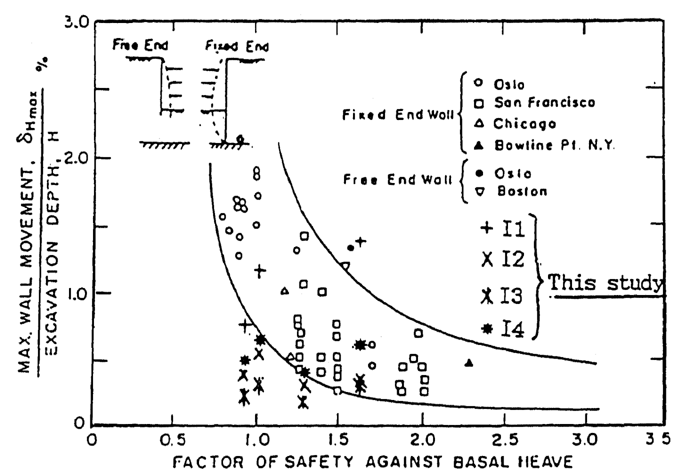


Figure 6 Relationship between wall deflection ratio and safety factor against basal heave

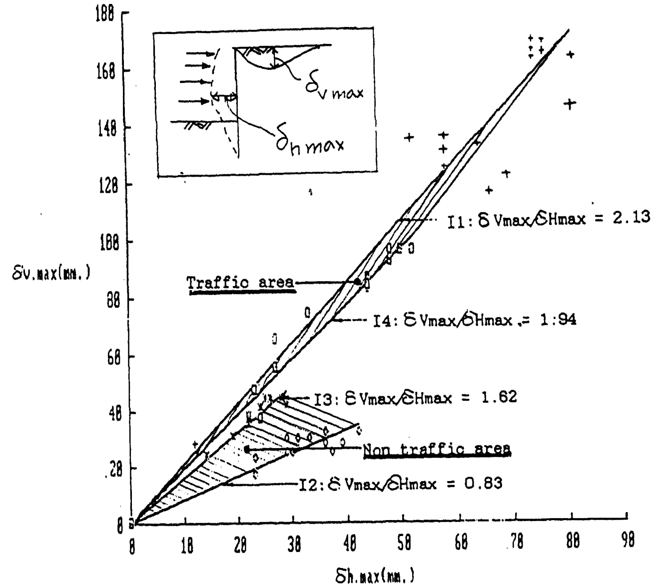
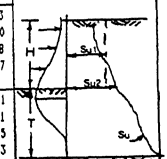


Figure 7 Relationship between maximum ground surface settlement and maximum wall deflection

Table 2 Summary of maximum wall deflection and safety factor against basal heave

Inclino. no.	Excavation depth, H(m)	γH (t/sq.m)	Su1 (t/sq.m)	Su2 (t/sq.m)	T (m)	FS.	δHmax. (mm.)	δHmax/H (%)	Remarks.
I1 (B=50m.)	4.50	7.48	1.82	2.00	16.50	1.63	64.00	1.42	
	7.00	11.39	1.78	1.86	14.00	1.01	81.00	1.16	
	9.50	15.30	1.87	2.21	11.50	0.92	74.00	0.78	
I2 (B=50m.)	4.50	7.48	1.82	2.00	16.50	1.63	15.00	0.33	
	7.00	11.39	1.78	1.86	14.00	1.01	42.00	0.60	
	9.50	15.30	1.87	2.21	11.50	0.92	36.00	0.38	
	11.30	18.15	2.06	3.60	9.70	1.30	31.00	0.27	
I3 (B=55m.)	4.50	7.48	1.82	2.00	16.50	1.63	14.00	0.31	
	7.00	11.39	1.78	1.86	14.00	1.01	22.00	0.31	
	9.50	15.30	1.87	2.21	11.50	0.92	24.00	0.25	
	11.30	18.15	2.06	3.60	9.70	1.30	26.00	0.23	
I4 (B=55m.)	4.50	7.48	1.82	2.00	16.50	1.63	27.00	0.60	
	7.00	11.39	1.78	1.86	14.00	1.01	44.00	0.63	
	9.50	15.30	1.87	2.21	11.50	0.92	44.00	0.46	
	11.30	18.15	2.06	3.60	9.70	1.30	48.00	0.42	

Note :
H = Depth of Excavation
T = Thickness from excavation depth to firm layer
FS = Factor of Safety against basal heave
S_{u1} S_{u2} = Uncorrected field vane shear strength

Figure 8 shows the relationship between the ratio of maximum sheet pile wall deflection to maximum excavation depth and berm width for excavation depth of 4.5 m, 7.0 m, 9.0 m. and 11.3 m., respectivity. It is clear that the effect of berm width is significant in reducing of maximum lateral wall deflection especially at the shallow excavation stage, however, does not effective in deeper zone of excavation. This might be due to the influence of increasing of soil shear strenght with depth.

COMPARISON OF PREDICTION AND FIELD PERFORMANCE OF MAXIMUM LATERAL SHEET PILE WALL DEFLECTION

The prediction of maximum lateral sheet pile wall deflection ($\delta_{H\ max}$) was carried out based on the simplified method proposed by Wong & Brom (1989). The measurement for the comparison was based on the excavation area at zone II or at the inclinometer number I_2, I_3 and I_4, where the final excavation depth is at the same level of

Table 3 Summary of maximum wall deflection and berm width

Inclino-meter No.	Working day	Excavation Depth,H(m)	Berm Width, W(m)	H max (mm)	H max/H (%)
I1	25	4.50	7	66	1.47
	30	4.50	4	69	1.53
	44	7.00	14	52	0.74
	46	7.00	10	58	0.83
	67	7.00	0	81	1.16
	78	9.50	12	74	0.78
	81	9.50	6	74	0.78
	88	9.50	0	74	0.78
I2	35	7.00	8	23	0.33
	44	7.00	2	37	0.53
	51	7.00	0	42	0.60
	79	11.30	11	36	0.32
	86	11.30	8	36	0.32
	93	11.30	6	36	0.32
I3	16	4.50	11	0	0.00
	23	4.50	0	14	0.31
	28	7.00	21	14	0.20
	35	7.00	13	19	0.27
	44	7.00	0	22	0.31
	51	9.50	15	22	0.23
	65	9.50	4	24	0.25
	72	9.50	0	28	0.29
I4	16	4.50	7	23	0.51
	23	4.50	0	27	0.60
	28	7.00	12	27	0.39
	35	7.00	8	33	0.47
	44	7.00	0	44	0.63
	51	9.50	17	44	0.46
	58	9.50	0	44	0.46
	79	11.30	12	48	0.42
	86	11.30	0	50	0.44

11.3 m. No surface surcharge load at this area was assumed , because the earth hauling truck was strictly allowed only on the platform. Table 4 summarized the parameters, estimated maximum lateral wall deflection and the average value of field performance. The reference firm layer was assumed at the silty sand layer at about 21 m. deep. Figure 9 compares the prediction of maximum lateral wall deflection with the field performance. The prediction of maximum lateral wall deflection agrees well with the measurement only at the final stage of excavation (H = 11.3 m.), however, at the intermediate stages of excavation (H = 4.5, 7.0 and 9.5 m.) the predictions were higher than field performances.

Table 4 Summary of soil parameters and predicted δ_H max

Excavation Depth H(m)	$\sigma_v = \gamma H$ (t/m^2)	T (m)	E_{s_2} (t/m^2)	T/E_s	δ_H max/H (%) Wong & Brom (1989)	Average field performance
4.5	7.18	16.5	1170	2.24	0.78	0.41
7.0	11.09	14.0	1320	1.69	0.59	0.51
9.5	15.02	11.5	1528	1.19	0.42	0.36
11.3	17.86	9.7	1737	0.88	0.31	0.31

Note : T is the thickness beneath excavation to firm layer
E_s is secant undrained modulus (from Pressuremeter test)

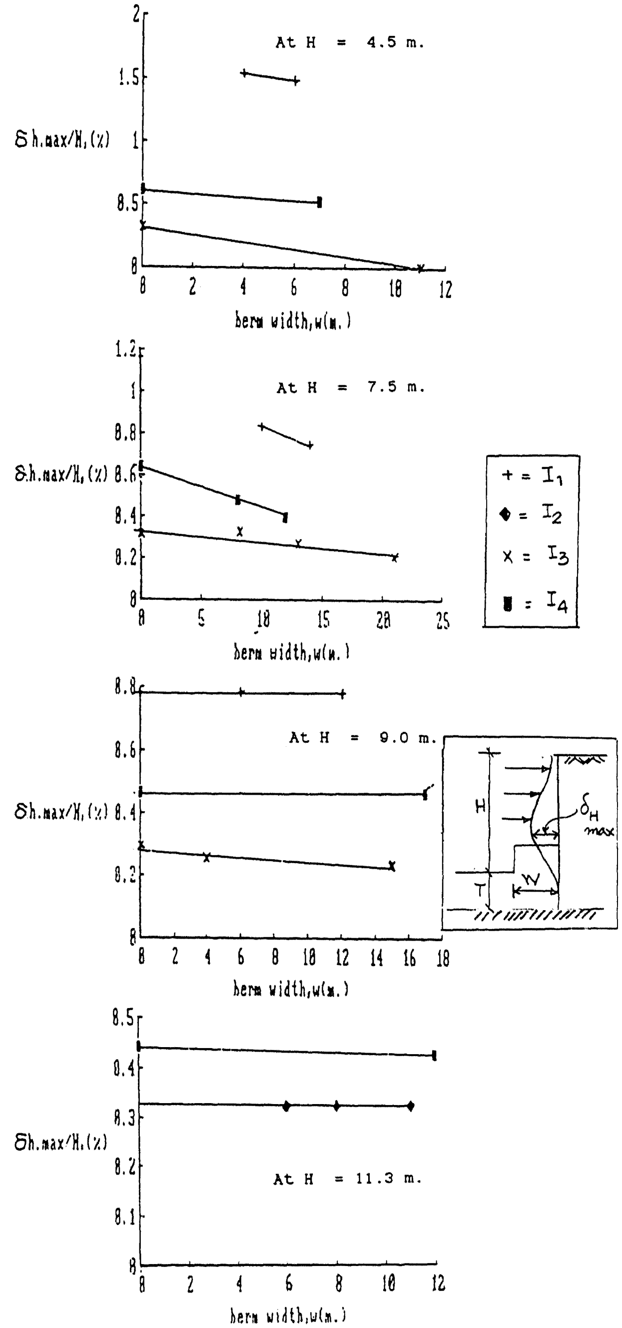


Figure 8 Relationship between maximum wall deflection and berm width

CONCLUSIONS

Based on the measurement and prediction of the behaviour of sheet pile wall for deep excavation in soft Bangkok clay, it can be concluded that :

- Mode of sheet pile wall deflection is the ratation about the bottom or fixed and type
- Traffic behide the sheet pile wall shows significant influence on the maximum surface settlement and maximum lateral wall movement

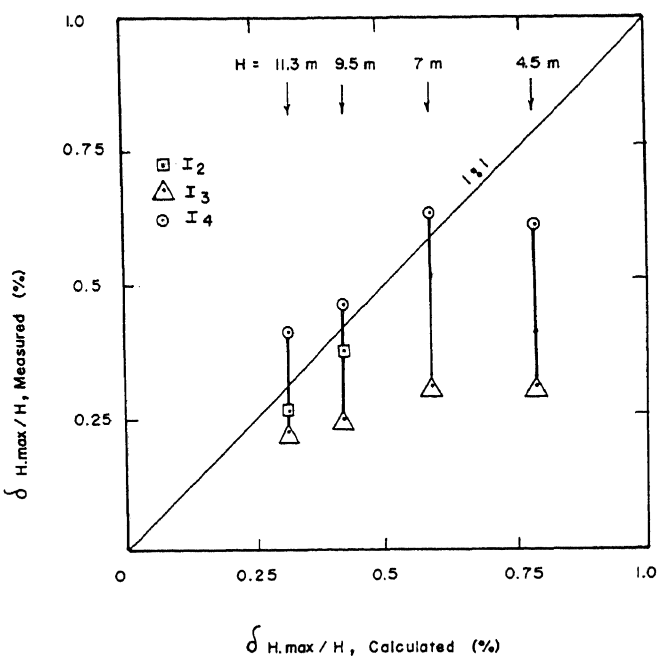


Figure 9 Comparison of lateral wall deflection between prediction and field measurement

- Berm width can reduce the maximum lateral wall deflection only at the first three stages of excavation
- The measured deflection ratio agaist safety factor against basal heave tends to lower than those proposed by Mana & Clough (1981)
- The prediction of maximum wall movement by the simplified method proposed by Wong & Brom (1989) agrees well with the field performance only at the final stage of excavation.

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