

BEHAVIORS OF STRUT BRACED SHEETPILE WALL IN SOFT GROUND EXCAVATIONS

by

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Behaviors of Strut Braced Sheetpile Wall in Soft Ground Excavations

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SYNOPSIS

Four case records of sheetpile retained excavation in soft grounds in Taipei and Singapore are presented. Behavior of sheetpile wall and associated ground settlement at various stages of excavation and bracing are related to the construction activities and found to be time dependent. Comparison of behaviour of sheetpile wall was made with that of diaphragm wall at a same site.

INTRODUCTION

Sheetpiles are commonly used for support of soft ground excavation to depths up to two stories of basement. Excavation to 6-8m deep, however, are often beyond the 'critical depth' of excavation in soft soils. Sheetpile movements are known to be related to a number of factors. PECK (1969) has summarized the relationships between total ground settlement behind sheetpile wall with distance from the wall in different types of soils. MANA and CLOUGH (1981) proposed a method for predicting movements of braced excavation in clays. In both papers not much discussions have been given to movements of braced excavation with marginal factor of safety against basal heave. For site of low stability, prediction of total ground settlement due to excavation is never accurate since the ground settlements are affected by many construction factors. The Paper presents instrumentation data from four excavation sites in Taipei and Singapore with very low factors of safety.

SITE CONDITIONS AND INSTRUMENTATIONS

The general subsoil conditions in Taipei and Singapore are described in MOH and OU (1979), and TAN & LEE (1977). The basic data of the four excavation sites are shown in Table 1 and their soil properties are summarized in Table 2. At every site, instrumentations including inclinometers, piezometers, vibrating

strain gauges and settlement points were installed. Inclinometer tubes were installed behind sheetpiles to deeper depth, than the sheetpile wall so that the lateral movement of soils below the sheetpile wall could be monitored. Ground settlements were measured with a surveyor's level.

INSTRUMENTATION RESULTS AND DISCUSSIONS

Excavations are carried out in step-wise processes of excavation and support installation. The following sections present and discuss data obtained during and after each stage at the four sites.

TABLE 2 Summary of Soil Data

Site	Depth	Soil Profile	γ_c KN/m ³	w_n %	s_u KN/m ²
A	0-2m	backfill	17.4	44	-
	2-20m	very soft to soft silty clay and clayey silt	17.6	34-43	19-34
	20-31m	medium silty clay and clayey silt	18.2	30-36	54
B	0-1m	fill	-	28	-
	2-6m	very soft clayey silt or silty clay with organics	17.6	35-45	14
	6-10m	silty fine sand with organics	18.1	30-34 (N=5)	-
	10-28m	very soft silty clay with organics	17.3	43-50	20-40
C	0-1m	fill	-	-	-
	1-4m	loose silty fine sand	18.4	-	(N=3)
	4-18m	very soft marine clay	15.5	60-80	20-30
	18-21m	loose clayey silty sand	17	50	(N=6)
	21-27m	very soft marine clay	15.5	60	38
D	0-3m	fill and very soft organic clay	14.1	93	9
	3-18m	very soft marine clay	15.16	50-100	10-20
	18-30m	completely weathered granite	-	-	-

Table 1 Basic Data of the Four Sites

Site	A	B	C	D
Location	Taipei	Taipei	Singapore	Singapore
Site Area, m x m	54 x 43	54 x 25.5	82 x 55	110 x 70
Excavation Depth, m	7.65	7.1	6.3	6.5, 7.4
Sheetpile Type	NKSP-III	NKSP-III	FSPIIIA	YSPIV
Sheetpile Length, m	16	16	24	24
Layers of Strut	3	3	3	3
Strut Level, m	0.82, 2.5, 5.5	0.5, 2.3, 5.3	0.6, 1.5, 4.4	1, 2.8, 4.8
Size of Strut, kg/m, 1st	H250 x 250 x 72	H300 x 300 x 94	H356 x 368 x 109	H300 x 300 x 94*
2nd	H300 x 300 x 94	H350 x 350 x 137	H356 x 368 x 109*	H300 x 300 x 94*
3rd	H350 x 350 x 137	H350 x 350 x 137	H356 x 368 x 132*	H300 x 300 x 94*
Unsupported Length of Strut, m	4.5	6	Varies 6 - 10	8.4
% Preloading to Design Load	20 - 30	30 - 32	30	20 - 30

*Note : in pairs

Lateral Soil Movement and Ground Settlement after Initial Excavation

At all four sites, initial excavation was carried out inside the sheetpile wall unbraced to a depth of about 1.5m. The sheetpile walls started to move inward as soon as the excavation was proceeded. In all cases, the lateral wall movement was largest at the top of the unbraced cantilever sheetpile. Lateral movement, however, did not cease at the excavation level but extended to great depth even beyond the depth of sheetpiles as shown in Table 3. It is obvious that the lateral movements are affected by the type of the top fill, the sheetpile alignment, stiffness of the sheetpile and site activities such as surcharge load and traffic movement. Monitored data also show that the lateral movements continued to increase even after excavation and substantial amount of heave had occurred in association with the excavation operation.

As the result of lateral movements of the sheetpile wall, settlements or subsidences occurred in the surrounding grounds. Fig 1 shows the relationship between the amount of ground settlement due to the initial stage of excavation with distance behind the wall. Maximum ground settlement always occurred right next to the wall and the amount of settlement decreased with increasing distance from it.

The initial stage of excavation is usually carried out before placement of the first layer of strut. The practice could result in significant lateral movements and ground settlements as seen in Sites A and D. Less initial movements and ground settlement could be anticipated if trenches for struts and walers were dug and the first layer of support was installed prior to carrying out the overall excavation.

Table 3 Lateral Soil and Wall Movements During Initial Excavation before Bracing

Site	A	B	C	D
Depth of Excavation, m	1.5-1.7	1.7	1.3	1.5
Sheetpile top Movement, cm	3.2-14.5	1-4.3	0.8-1.8	6.6-15.0
Depth of Soil Movement, m	16-26	6-27	22	13-25
Max Ground Settlement, cm	0.4-7	N.A.	0.8	5.3-14.4

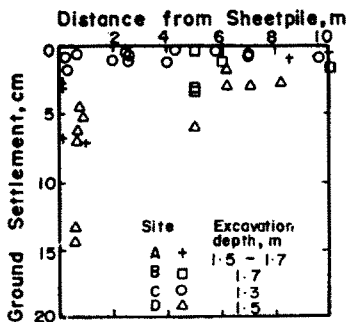


Fig. 1 Ground Settlements Due to Initial Excavation Without Bracing

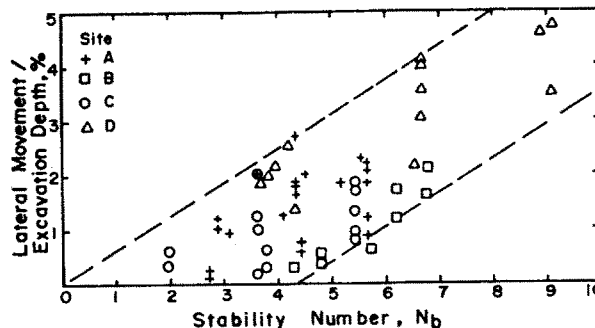


Fig. 2 Relationships between Sheetpile Movements and Stability Numbers

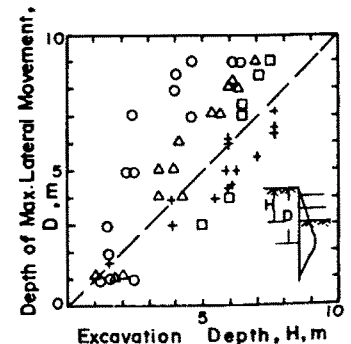


Fig. 3 Depth of Maximum Lateral Movement vs Depth of Excavation

Movements of Struttred Excavations

With the first layer of bracing in place, the subsequent excavations and installations of bracings cause the sheetpile wall to deflect inward in a bulged shape. The size of the bulge increases with depth of excavation and the maximum point of deflection moves downward with depth of excavation. Fig 2 presents the sheetpile movements measured at the four sites against their stability numbers, $N_b = \gamma H / s_u$, where γ is the unit weight of soil, H is the excavation depth and s_u is the undrained shear strength of the soil. The parameter N_b (PECK, 1969) is adopted instead of safety factor (TERZAGHI, 1943) mainly because movements monitored are more related to excavation depths. Although the data are rather scattered due to the effects of other influential factors such as strut stiffness, strut spacing, construction schedule, surcharge loading etc, nevertheless, a clear trend can be seen. With the help of the embedded support of the sheetpiles, excavation even beyond the critical depth (i.e. $N_b \approx 5.7$) is still possible, but larger lateral movements must be tolerated.

The positions of the maximum horizontal movements of the sheetpile walls after each step of excavation were found to be near the excavation surfaces with a strong tendency to be at about 2m below the excavated surfaces, particularly when the excavation depths approached the critical depths, as shown in Fig 3.

The rate of lateral movement of sheetpiles changes with time, excavation depth and bracing installation. Fig 4 illustrates the effect of time on lateral wall movement and Fig 5 shows the rate of wall movement as a function of excavation depth. These two plots clearly show that the rate of lateral movement is time dependent and also depth dependent. Fig 5 shows that the depth of excavation increases, which means that the soil is approaching its critical state, the rate of lateral movement increases. For excavation at a particular depth, the rate decreases with time when the excavation stability is still high. When the total lateral movement had already reached or near the soil's plastic state, the rate of lateral movement may continue or even increase with time until the next bracing support is installed. Timely installation of struts is extremely important to control lateral movement and thus ground settlement.

During the process of braced excavation, more soils tend to move into the excavation as excavation depth

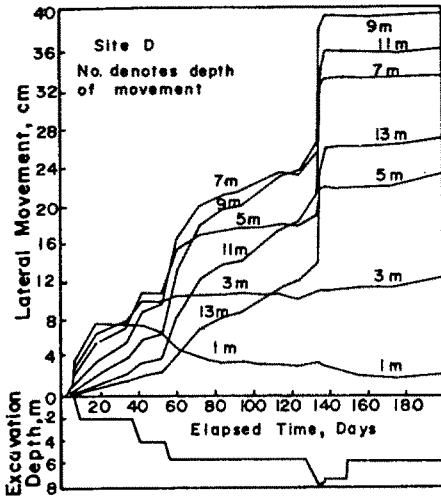


Fig. 4 Illustration of Effect of Time on Lateral Wall Movement

increase, thus larger ground settlement and greater extend of the effect occur as shown in Fig 6. Lateral soil movement and the associated ground settlement usually occur fairly rapidly during or immediately after excavation. The soil deformation can be considered to occur in essentially undrained state. Therefore, theoretically, the volume of soil moved laterally towards the excavation should equal to the volume of soil settled vertically adjacent to the excavation. It can be noticed in Fig 7 that the volume ratios of lateral movement to vertical settlement are fairly close to one.

Movements Due to Construction of Basement and Removal of Strutts

As soon as an excavation reached the design level, immediate casting of a layer of plain concrete close to the sheetpiles had shown to be very effective to arrest the sheetpile movements. (Table 4).

Table 4 Effect of P C Slab at Bottom of Excavation of Lateral Movements

Site	Rate of Lateral Movement mm/day		Thickness of P.C. Slab, mm
	Before Casting P.C. Slab	After Casting P.C. Slab	
A	10	2	100
B	30	2	200
C	4	0.7	150
D	19	4.2	75

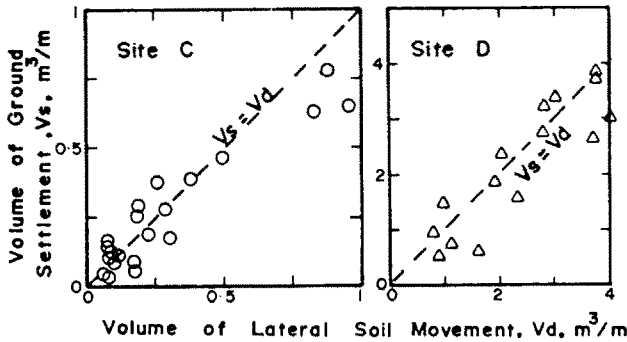


Fig. 7 Relationship between Ground Settlement and Lateral Soil Movement

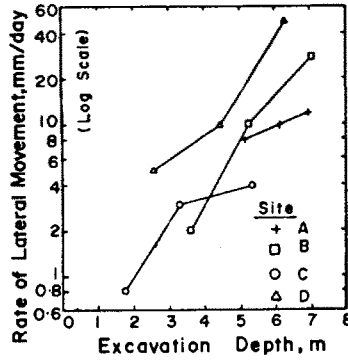


Fig. 5 Rate of Wall Movement as Function of Excavation

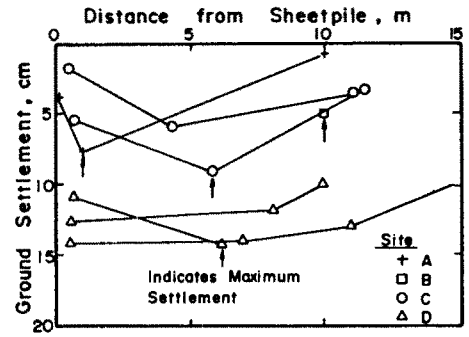


Fig. 6 Ground Settlement During Braced Excavation

Monitoring results indicate that removal of struttings will also increase lateral movements of the sheetpiles and thus cause additional ground settlement. Fig 8 presents the ground settlements at 3 sites at the stage of basement construction. The basement raft and wall was either cast against the sheetpile wall or at some distance away from the wall.

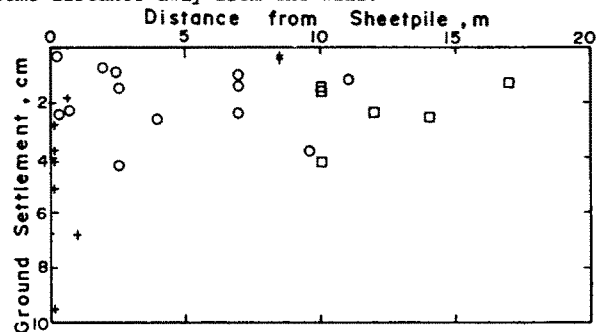


Fig. 8 Ground Settlements due to Removal of Struts

For basement walls cast against the sheetpile wall (Sites C and D), the removal of struts resulted in very little movement. For other cases, the gaps between the two walls had to be backfilled and movements of the sheetpile after removal of the struts would be dependent upon the effectiveness of the backfills. At Sites A and B, instead of using only backfill materials, concrete beams were cast at each basement slab level to brace the sheetpiles to the structures. Very little movement was observed at the levels of the reinforced beams as shown in Fig 9. Also shown in the same figure, large movements were recorded at locations where no additional supports were installed.

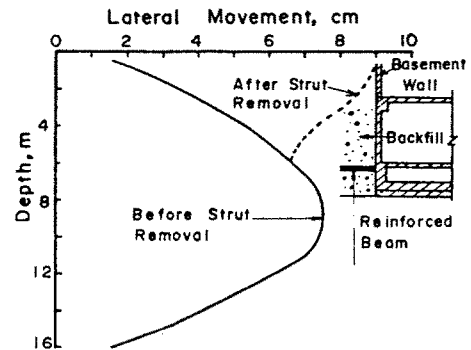


Fig. 9 Effect of Reinforced Beam on Lateral movement due to Removal of Strut

Some projects require extraction of the sheetpiles after completion of basement construction. In very soft ground, soils may adhere onto the sheetpile surface and be extracted together with the sheetpiles thus leaving voids in the ground. Close up of the voids will cause lateral movement, ground settlement, and settlement of the raft which is usually at a shallower depth than the sheetpile penetration. Ground movement and settlement responding to sheetpile extraction are rapid and immediate, as illustrated in Fig 10. Immediate settlements of the raft were recorded as shown in Fig 11 with larger settlements along the edges and particularly at the corners.

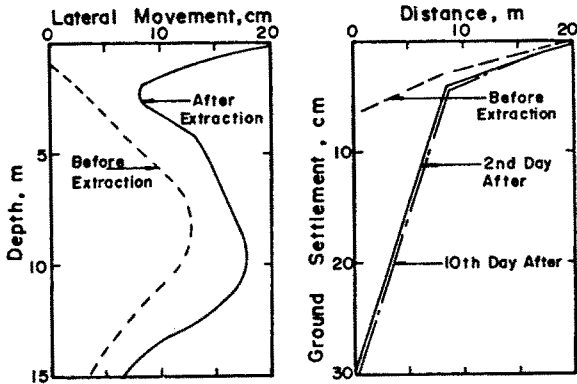


Fig. 10 Ground Movements due to Extraction of Sheetpile

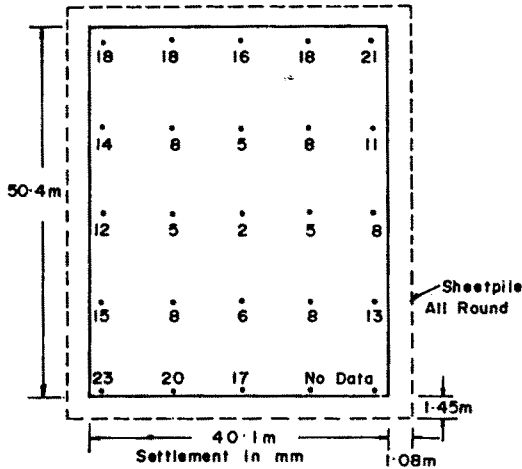


Fig. 11 Settlement of Raft due to Extraction of Sheetpile

Comparison of Performance of Sheetpile Wall With Concrete Diaphragm Wall

At Site B, the basement consists of two rectangular cells interconnected into a L-shape structure. Each cell had similar excavation depth of 7.1m, but with slightly different site area. One cell was retained by 16m long sheetpile wall, whilst the other cell was retained by a 60cm thick reinforced concrete diaphragm wall of similar length. Similar struts were installed at identical depths. The cell with sheetpiles was excavated first till completion of the basement structure which was then followed by excavation of the cell with diaphragm wall. The twin cells at this site with different types of retaining wall give some interesting performance data for comparison as summarized in Table 5. Both cells showed similar amount of upheave and strut loads. Due to the higher rigidity of the

diaphragm wall, the lateral wall movement was only 1/3 of that of the sheetpile wall, resulting 50% less in ground settlement. This indicates that diaphragm wall is a better system for control of ground settlement in excavation. The semi-rigid wall, however, appeared to have no effect on the amount of settlement of the raft foundation.

Table 5 Comparison of Performance of Sheetpile Wall with Concrete Diaphragm Wall

	Sheetpile	Diaphragm Wall
Area m x m	54 x 25.5	64 x 24.5
Size	NKSP-III	60cm thick
Length, m	16	16
Heave, cm	7.2	7.2
Groundwater Pressure	Static	Static
Max. Lateral Movement, cm	14.5	5
Ground Settlement, cm	6.3	3.0
Raft Settlement after basement completed, cm	1.06±0.2	1.02±0.67
Ave. Strut Load, tons	33, 67, 112	47, 75, 115

CONCLUSIONS

On the basis of instrumentation monitored data at four excavation sites in soft ground with sheetpile retaining system, the following conclusions are drawn:

1. When proper construction sequence is adopted, excavation can be carried out beyond the critical depth with marginal factor of safety.
2. Soil movement, can be greatly reduced by limiting the depth of unbraced excavation with trenches for installing the first layer of struts.
3. Timely installation is extremely important in controlling lateral movement and ground settlement.
4. Casting of a plain concrete slab at bottom of excavating is a very effective way to reduce further lateral soil movement.
5. Rigid diaphragm wall retaining system has much less lateral soil movement but does not appear to have much effect on the amount of raft settlement as compared to the more flexible sheetpile system.

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