SETTLEMENTS INDUCED BY DEEP EXCAVATIONS IN TAIPEI

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Settlements Induced by Deep Excavations in Taipei

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SYNOPSIS This paper describes the ground settlement behavior induced by deep excavations in the Taipei soil. Settlement data from 8 typical excavations located at different sites within the T2 Zone of the Taipei Basin are analyzed in order to define a generalized settlement profile for future design. Settlements in the directions perpendicular and parallel to diaphragm walls are studied. The T2 Zone which covers the central area of the Taipei is characterized by layered deposits of clayey and sandy soils. This paper puts emphasis on the nature of soil deposits in the T2 Zone and relates ground settlement behavior to excavation geometry. The lateral movements of diaphragm walls used to support the excavations are also described.

INTRODUCTION

In a highly urbanized area such as Taipei, a reliable prediction of ground settlement around an excavation is critical as these settlements directly affect adjacent structures and facilities. Up to the present, the basis for predicting such settlements has remained largely empirical (e.g. Clough and O'Rourke, 1990, Nicholson, 1987). Although the finite element method has become popular in recent years (e.g. Whittle et al., 1993) the technique still requires refinements particularly in dealing with uncertainties in estimating soil properties, modelling stratigraphic variations, simulating groundwater behavior, modelling the construction sequence and others. Performance data from actual excavation cases in similar conditions can provide a valuable basis in formulating empirical solutions that can take into account all of these uncertainties.

Excavations supported by diaphragm walls have been widely used in Taipei, primarily for construction of deep basements for buildings and similar structures (Moh and Ou, 1979, Moh and Song, 1984). Good quality field monitoring data from these excavations such as settlement and wall deflection are available. This paper presents an analysis of settlement data based on 8 selected cases with similar conditions, e.g., geologic, as shown in Fig. 1. More detailed information on the cases are given in Fig. 2 and described in Table 1.

SUBSOIL CONDITIONS

The T2 Zone is an areal sub-division of the Sungshan deposits in the Taipei Basin (Moh and Associates Inc., 1987). The Sungshan formation consists of a reasonably well-defined sequence of alternating layers of clayey and sandy soils.

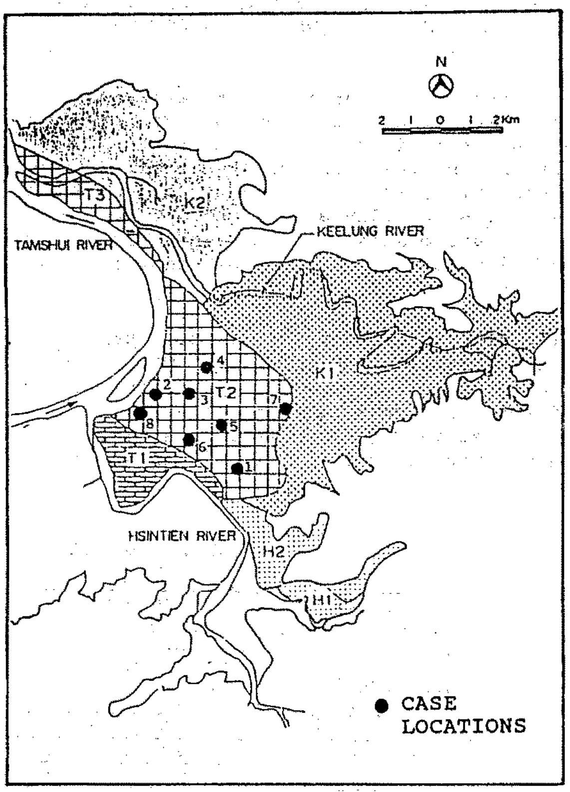

FIG. 1 AREAL SUB-DIVISIONS OF THE SUNGSHAN DEPOSITS AND LOCATIONS OF EXCAVATION CASES

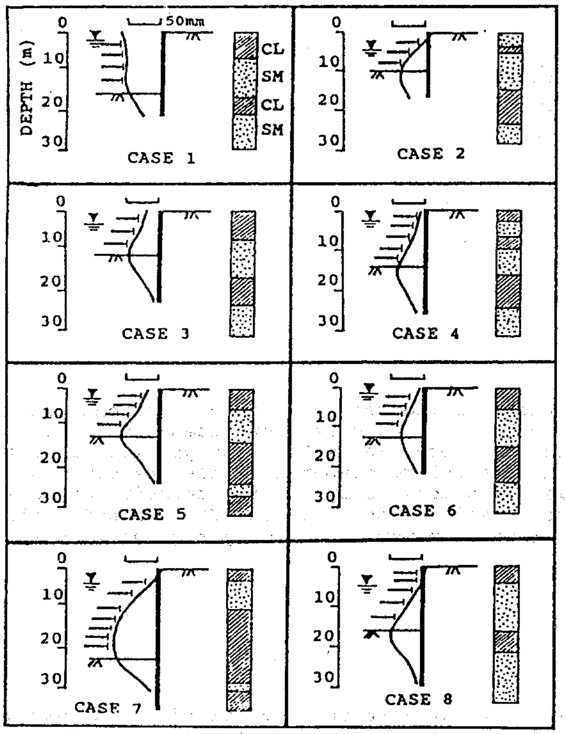

FIG. 2 PROFILES OF EXCAVATION CASES AND LATERAL MOVEMENT OF DIAPHRAGM WALLS

Six major stratigraphic layers are identified as shown in Table 2. The Sungshan Formation which varies in thickness between 40 to 70 m, is underlain by the Chingmei Formation. In summary, layers 6, 4, and 2 of the Sungshan Formation comprise silty clay and clayey silt while layers 5 and 3 are basically silty sands. The Chingmei Formation consists mainly of sandy gravels and cobbles.

The T2 Zone covers the central part of the Taipei Basin. Within the T2 Zone, the stratigraphy is not entirely uniform as can be reflected in the subsoil profiles indicated for each case in Fig. 2. Typical engineering and index properties for each soil layer are shown in Table 3.

TABLE 1 SUMMARY OF EXCAVATION CASES

	EXCAVATION CASE	EXCAVATION GEOMETRY (M)			DIAPHRAGM WALL		NUMBER OF STRUT LEVELS
		DEPTH H	LENGTH L	WIDTH B	DEPTH (M)	THICKNESS (cm)	
1	TAIWAN POWER	16.2	91	61	21	70	4
2	KUAN MIN	11.1	70	52	17	60	3
3	CENTRAL INSURANCE	11.4	53	35	23	60	3
4	CHUN WEI	14.7	45	37	27	70	5
5	CHUNG YANG PAI SHI	12.3	44	37	25	60	4
6	SHIN-I	12.6	49	48	22	60	4
7	CATHAY LIFE (MIDDLE SEC.)	21.7	65	46	34	70	7
8	CHINA TIMES	17.1	70	40	30	70	5

TABLE 2 PROFILE OF SOIL DEPOSITS IN THE TAIPEI BASIN

FORMATION		THICKNESS (M)		SOIL DESCRIPTION
TOP SOIL (CL, CL/ML)		1-6		YELLOWISH BROWN CLAY
SUNGSHAN FROMATION	LAYER VI (CL/ML)	2-8	40-70	GRAYISH BLACK CLAYEY SILT
	LAYER V (SM)	2-20		GRAY SILTY FINE SAND
	LAYER IV (CL/ML)	6-29		GRAY SILTY CLAY
	LAYER III (SM)	0-19		GRAY SILTY FINE SAND
	LAYER II (CL/ML)	0-19		GRAY SILTY CLAY
	LAYER I (SM)	0-15		GRAY SILTY FINE SAND
CHINGMEI FORMATION		0-200		YELLOWISH BROWN GRAVEL

GROUNDWATER CONDITIONS

Extensive pumping from the underlying Chingmei Formation for about 20 to 30 years prior to the 1970's has caused the piezometric conditions below layer 4 in the T2 Zone to be sub-hydrostatic with respect to the original water table (Chin et al., 1991a). This condition is reflected in the typical groundwater distribution on the active side normally assumed in the current design practice for excavations in the T2 Zone (Wong et al., 1993) as shown in Fig. 3. On the passive side, a hydrostatic pressure distribution below excavation level can normally be achieved by dewatering. For the cases considered in this paper, a hydrostatic water pressure distribution on the passive side was generally achieved during construction. This condition is reflected on the stress paths for a soil element on the passive side of a 12 m

TABLE 3 PROPERTIES OF SOIL DEPOSITS IN THE T2 ZONE

LAYER	SPT-N VALUE (blows /30cm)	DRY UNIT WEIGHT (KN/m^3)	WATER CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	COMPRESSIBILITY Cc	COMPRESSIBILITY Cv (cm2/sec)	SHEAR STRENGTH Su (kg/cm2)	SHEAR STRENGTH c' (kg/cm2)	SHEAR STRENGTH φ' (deg)	PERMEABILITY kv (cm/sec)
VI	5	14.5	31.2	35.8	12.9	0.29	5.6E-03	0.44	0	33.6	4.4E-07
V	10	15.4	26.3	--	NP	--	--	--	0	32.5	2.6E-04
IV	8	14.3	32.1	34.3	12	0.39	6.4E-03	0.53	0	32.3	1.4E-06
III	21	16.1	23.9	--	NP	--	--	--	0	33.3	1.7E-04
II	19	15.5	27.2	30.3	9.2	0.33	8.3E-03	0.53	0	35.5	1.4E-05
I	31	17.0	20.3	--	NP	--	--	--	0	34.2	--

excavation in the T2 Zone (Chin et al., 1991b) as shown in Fig. 4. The water pressure on completion of excavation is consistent with a hydrostatic pressure distribution with respect to the excavation base.

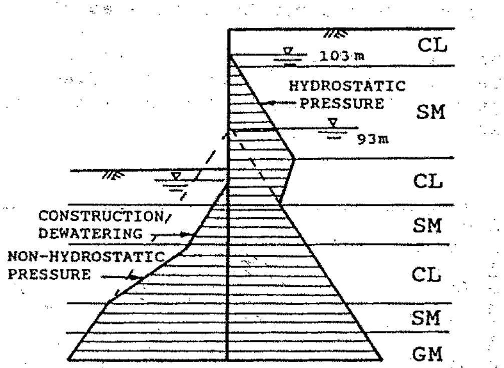

FIG. 3 TYPICAL DESIGN WATER PRESSURE PROFILE FOR TYPICAL EXCAVATIONS IN THE T2 ZONE (AFTER WONG ET AL., 1993)

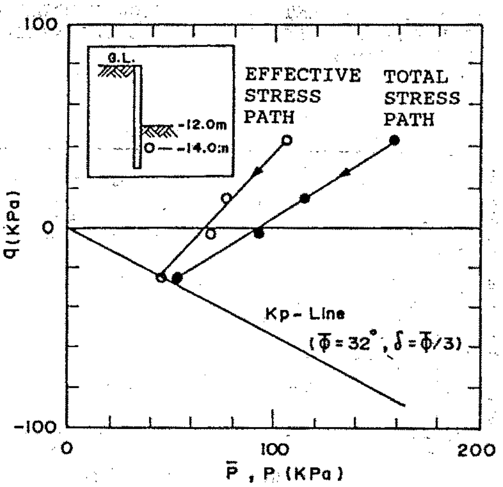

FIG. 4 STRESS PATHS FOR A SOIL ELEMENT IN THE PASSIVE ZONE OF A TYPICAL EXCAVATION IN THE T2 ZONE (AFTER CHIN ET AL., 1992)

EXCAVATION CASES

The excavation cases used in the analysis have been presented in Table 1 and Fig. 2. It is emphasized that these cases represent the typical excavation for basements in Taipei. Excavation depths vary between 11 to 22 m. Diaphragm walls 0.60 to 0.70 m thick and between 17 to 30 m long have been used as excavation support. The excavations were all internally-braced by struts and constructions were all carried out using the bottom-up method. The length-to-width ratios of the excavation areas vary between 1.0 to 1.7.

MONITORING DATA

For each case, good monitoring data were obtained from inclinometers within diaphragm walls and ground surface settlement points, among others. The data used in this paper include only those from:

(1) settlement points arranged along a line perpendicular to the diaphragm wall at midspan
(2) settlement points arranged along a line parallel to the diaphragm wall
(3) inclinometers positioned very close to the settlement points described in (1)

It is emphasized that the settlement data refers to total settlements which occurred after the final excavation stage (i.e. before casting the base slab), hence, the effect of trenching and wall installation, wall deflection during main excavation and consolidation due to dewatering are all included. From a closer analysis of available data up to the final construction stage, it is noted that in most cases, the maximum settlement occurred after the final excavation stage. It is further emphasized that the settlement data include the effect of rigidity of existing adjacent buildings and structures. From available information, only those data which were noted to have been unaffected by any significant leakage of soil through diaphragm wall imperfections or damaged by construction equipment are included.

GROUND SETTLEMENT

Settlement Profile

Settlement profiles in the direction perpendicular to the wall for 7 excavation cases are plotted in Fig. 5. The settlement envelope for excavations in the T2 Zone as proposed by Woo and Moh (1990) is indicated in the figure. Note that three of the cases are represented by more than 1 set of data. The reason is simply due to the availability of more than 1 set of good settlement data for those cases. As can be observed, the settlement trough is characterized by 3 distinct modes:

(1) Significant sagging occurs from the face of the wall to a distance of about 0.5 times the excavation depth (H).
(2) Significant hogging occurs between 0.5 to 1.5 H from the wall.
(3) Gradual transition to a horizontal slope occurs beyond a distance of about 1.5 H from the wall.

Maximum settlements tend to occur at a distance of about 0.5 H from the wall. Settlements near the face of the wall are relatively small. It is considered that wall friction may have contributed in limiting the vertical flow of the soil near the face of the wall.

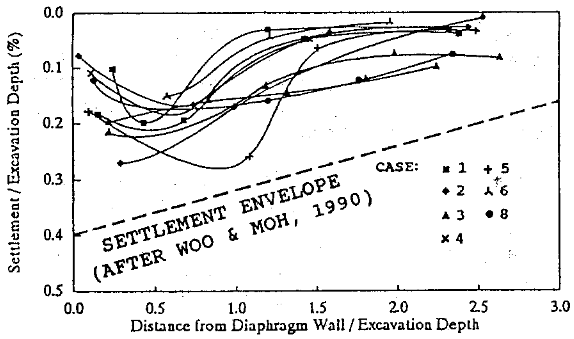

FIG. 5 SETTLEMENT PROFILES PERPENDICULAR TO DIAPHRAGM WALLS FOR TYPICAL EXCAVATIONS IN THE T2 ZONE

Corner Effect

Settlement data from available rows of settlement points parallel to the wall are plotted in Figs. 6 and 7. These rows of settlement points represent various distances from the wall, i.e. between 2 to 20 m. From the *figures*, the effect of corners on the distribution of settlement around a typical deep excavation can be observed. The cases considered in this paper have excavation depths ranging from 11 to 22 m; length to width ratios between 1.0 to 1.7; and length to excavation depth ratios between 3.0 to 6.3. Figure 6 suggests that the maximum settlements tend to occur within the middle 50 percent of the wall span. Settlements at corners are about 20 to 60 percent of the maximum settlements which occur around the midspan. Application to long excavations may be deduced from Fig. 7 where the settlement data have been correlated with excavation depth. The figure shows that the corner effect on settlements becomes insignificant at a distance equal to the excavation depth. The scatter of data in Figs. 6 and 7 can be attributed to certain factors such as variations in stratigraphy, construction procedures, bracing systems, and others.

Wall Deflection

Since the major source of settlement is the lateral movement of the wall, the general shapes of wall deflection as illustrated in Fig. 2 should be described. There are 2 significant points which can be observed:

(1) Maximum wall deflection of the wall generally occurs at about the maximum excavation depth.
(2) In all the cases, where the ratio of diaphragm wall length to excavation depth ranges from 1.3 to 2.0, there was lateral displacement of the wall toe. The displacement can be as much as 25 mm.

Further analysis can be carried out to correlate settlement with wall deflection. The subject is however, beyond the scope of this paper.

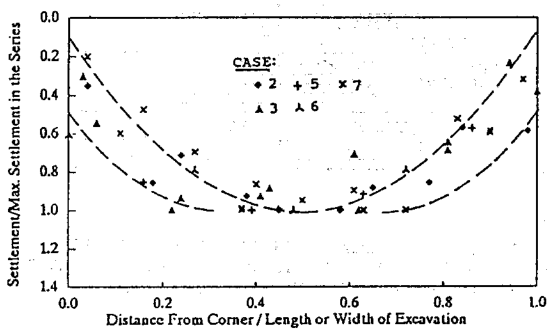

FIG. 6 SETTLEMENT DISTRIBUTION PARALLEL TO DIAPHRAGM WALLS FOR TYPICAL EXCAVATIONS IN THE T2 ZONE

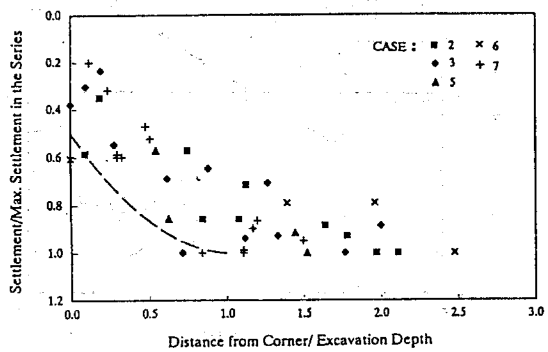

FIG. 7 RELATIONSHIP OF SETTLEMENT PARALLEL TO DIAPHRAGM WALLS AND DEPTH OF EXCAVATION

CONCLUSIONS

The behavior of ground settlement around typical deep excavations in the T2 Zone of the Taipei Basin has been analyzed using data from 8 excavation cases. Based on the study, the following conclusions can be made:

(1) The settlement profile perpendicular to the wall can be divided into 3 distinct zones: zone of significant sagging, zone of significant hogging, and zone of gradual transition.
(2) Perpendicular to the wall, the maximum settlement tends to occur at a distance equal to half the excavation depth.
(3) Parallel to the wall, the maximum settlement tends to occur within the middle 50 percent of the wall span.
(4) Near the corners, settlements are about 20 to 60 percent of the maximum settlement which occurs at midspan.
(5) Corner effect on settlement parallel to the wall tends to diminish at a distance from the corner equal to the excavation depth.

REFERENCES

Chin, C.T., Chieh, T.T. and Duann, S.W. (1991a). Groundwater Effect on MRT Construction. Proc. 1st Young Asian Geot. Engrs. Conf., Bangkok.

Chin, C.T., Crooks, J.H.A., Enriquez A.S., and Patron, B.C. (1991b). Design and Performance of Open Excavations in Taipei. Proc., 44th Canadian Geotech. Conf., Calgary.

Clough, G.W. and O'Rourke, T.D. (1990). Construction Induced Movements of In-situ Walls. ASCE Conf. on Earth Retaining Structures, Cornell University.

Moh and Associates, Inc. (1987). Engineering Properties of the Soil Deposits in the Taipei Basin. Report No. 85043, Submitted to the Ret-Ser Engineering Agency/ Taipei Public Works Department, Taipei, Taiwan.

Moh, Z.C. and Ou, C.D. (1979). Building Foundation Practice in Taiwan. Proc. 6th Asian Regional Conf. on Soil Mech. and Found. Engrg., Singapore, Vol. 2.

Moh, Z.C. and Song, T.F. (1984). Performance of Diaphragm Wall in Deep Foundation Excavations. Proc., Int'l. Conf. on Case Histories in Geot. Engrg., ASCE, Univ. of Missouri-Rolla, St. Louis.

Nicholson, D.P. (1987). The Design and Performance of Retaining Walls at Newton Station. Proc., Singapore Mass Rapid Transit Conf.

Whittle, A.J., Hashash, Y.M.A. and Whitman, R.V. (1993). Analysis of a Deep Excavation in Boston. ASCE J. of Geot. Engrg. Div., January.

Wong, L.W., Lin, H., and Patron, B.C. (1993). Design of Diaphragm Walls for TRTS Deep Excavations. Proc., Conf. on Taipei Metropolitan Rapid Transit Systems, Taipei.

Woo, S.M. and Moh, Z.C. (1990). Geot. Characteristics of Soils in the Taipei Basin. Proc., 10th Southeast Asian Geotech. Conf., Taipei, Vol. 2.