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B. Huang
Louisiana Transportation Research Center, Baton Rouge, Louisiana

L. Mohammad
Louisiana Transportation Research Center, Baton Rouge, Louisiana

Jianming Zhu
Shanghai Foundation Engineering Co., Shanghai, China

Xiaoping Zhu
Shanghai Environmental Protection Bureau, Shanghai, China

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DESIGN, CONSTRUCTION AND MONITORING FOR THE EXCAVATION OF SHANGHAI WORLD PLAZA

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B. Huang and L. Mohammad
La Transportation Research Ctr.
4101 Gourrier Ave.
Baton Rouge, LA 70808, USA

Jianming Zhu
Shanghai Foundation Engineering Co.
110 Yanan East Rd.
Shanghai 200002, P. R. China

Xiaoping Zhu
Shanghai Environmental Protection Bureau
1525 Pudong South Rd.
Shanghai 200002, P. R. China

ABSTRACT

The Shanghai World Plaza is a multi-function building located in Shanghai Pudong New Development Area. It is a steel structure with thirty eight stories (199m) above the ground and three stories of basement. The excavation area of this building is 75m by 100m. The depth of the excavation is 16m to 18m (kernel part). The construction site is covered with soft soils up to a depth of 25m. Main streets, pipelines and existing buildings surround the site.

The retaining structure employs a diaphragm with 1m in thickness, 30m in depth and 340m in total length. Three levels of H shaped steel supports are placed on 163 steel columns.

De-watering of groundwater was applied during the excavation in order to decrease the hydraulic gradient and to improve the soils at the bottom of the excavation.

Field monitoring includes 40 settlement/displacement points to cover main street pavements, pipelines and diaphragm units. Other items of monitoring include the excessive pore water pressure within the soils, multi-layer settlement, inclination of the retaining walls, lateral soil pressure, axial supporting force and, stresses within the diaphragm.

KEYWORDS

soft soil, diaphragm, deep excavation, retaining structure, de-watering, lateral movement, field monitoring

INTRODUCTION

The Shanghai World Plaza is a multi-function building located in Shanghai Pudong New Development Area. The main part of the building has thirty-eight stories (199m in height) above the ground and three stories of underground basement. The excavation area of this building is 75m by 100m and the depth of which is 16m to 18m (kernel part). The construction site is covered with soft soils within a depth of 25m. Main streets, pipelines and existing buildings surround the site.

DESIGN OF RETAINING STRUCTURE

The design of the retaining structure was performed by the Institute Special Structure Design of Shanghai Foundation Engineering Company. The primary objectives of the design are to ensure the safety of excavation and to minimize the effects of excavation to the surrounding buildings streets and pipelines. Based on local experience, underground diaphragm in conjunction with steel support is selected.

Geological Conditions

The construction site is of typical soft soil area terrain as in most part of Shanghai. Ground water level is about 1.2m below the ground. Ten soil strata were revealed within 100 meters through geotechnical site investigation. Table 1 outlines these soil layers and their main properties.

Retaining Structure

The retaining structure consists of reinforced concrete diaphragm and lateral steel supports. The diaphragm is 1.0m in thickness, 30m in depth and 340m in total length. The lateral steel support consists of horizontal steel beams and an average of 6.2m grid of 163 steel columns. The original design had four levels of H shaped steel bar supports. The third (lowest) level was dropped during the construction because of excavation difficulties. A stronger type of H shaped steel bars were used to replace the original ones and higher strength of plain concrete was applied to the bottom of the pit. Figure 1 and Fig.2 show the plan of the actual retaining structure.

Groundwater Dewatering

Dewatering is applied to reduce the hydraulic gradient at the bottom as the deepest excavation reaches 18m and the natural ground water table is only 1.2m below the ground level. Dewatering in this project consists of two parts. The first part consists of eight Φ560mm (250mm tube diameter) deep wells (48m in depth) outside the retaining walls. The design is to lower the water head by 8m to reduce the head difference. The estimated ground settlement is 10mm. The second part of dewatering is to lower the water lever down to -16m below the ground inside the retaining wall in order to facilitate the excavation. Two stages of light wells are applied along the retaining walls. Observation wells are designed to monitor the groundwater levels inside and outside the retaining system. Figure 2 shows the layout of the deep well systems.

FIELD MONITORING

Field monitoring plays an important part in this project. The objectives of field monitoring are to control the construction procedure, ensure the retaining structure performs as designed and prevent any hazardous impact to the surrounding environment. The monitoring items include the settlement and displacement points for the surrounding buildings, pavements and pipelines, excessive pore water pressure within the soils, multi-layer settlement, tilt of retaining walls, lateral earth pressure, axial supporting force and, stresses within the diaphragm (Fig. 3). The whole field monitoring of this project lasted for eighteen months.

Settlement and Displacement of Surrounding Objects

As the excavation site is surrounded by the existing building, main streets and pipelines, it is crucial that these objects be well protected. Forty settlement/displacement control points were set up to ensure that the ground movement be maintained within certain limits. Figure 4 shows the settlement of neighboring buildings at point s3 as a result of the excavation. It is also found that excavation induced settlement decreases with the increase of the distance from the site (Table 2).

This verifies the local empirical formula:

$$X = H_g * \tan(45 - \phi/2) \qquad (1)$$

where X is the maximum influence distance, H_g is the depth of the retaining wall and ϕ is the average friction angle of the soils. Here we have H_g=30m, $\phi_{ave}=13^0$, thus X=24m. There is little excavation-induced settlement beyond the distance of 24 meters (Table 2).

Horizontal Movement of the Retaining Walls

The horizontal movement of the retaining wall is largely determined by the sequence of the excavation. In this project, when the first layer of excavation is finished, the whole system moves toward northeast direction. The maximum displacement recorded is 123.6mm (at Top11, see Fig. 5), which is much greater than the empirical formula of 0.001H, where H is the depth of the retaining wall.

Lateral Earth Pressure

According to "Shanghai Design Code for Foundation Engineering", lateral soil pressures are calculated by the following equations:

$$p_a = (q + \Sigma\gamma_i h_i)K_a - 2cK_a^{1/2} \qquad (2)$$
$$K_a = \tan^2(45 - \phi/2) \qquad (3)$$
$$p_p = (q + \Sigma\gamma_i h_i)K_p + 2cK_p^{1/2} \qquad (4)$$
$$K_p = \tan^2(45 + \phi/2) \qquad (5)$$

where p_a is the active soil pressure, p_p is the passive soil pressure, q is the surcharge, c is the cohesion, K_a and K_p are the coefficients of active and passive soil pressure. It is shown that active earth pressure matches well between the calculation and the field observations while passive pressure does not (Fig. 6).

Axial Support Forces

The axial first level support force reaches its maximum value (900 to 1350kN) when the excavation of the first layer reaches the bottom. After the second level of support is installed, the forces at the first level decrease to around 450kN. This value stays throughout the whole process.

The forces on the second level of support increase as the excavation of the second layer deepens. The adding of the third layer of support does not reduce the axial force on the second layer of support. The supporting force at the second layer stays around 2000 to 2500kN and that of the third layer of support varies between 500 to 1000kN.

CONCLUSION

The overall design, construction and monitoring of this project have been a success. No major hazardous environmental impact occurred during the process. Following conclusions are drawn from this project.

- Successful excavation of large-scale deep foundations requires close cooperation among design, construction and field monitoring. Field monitoring plays a crucial role in the whole process.
- Groundwater de-watering reduces the hydraulic gradient and ensures a safe excavation. However, it should not cause too many disturbances to the environment.
- The excavation-induced settlement to neighboring structures is closely related to the excavation depth. The ratio between the excavation depth and the maximum influence distance is about 1:1.5 in this project.
- Theoretical calculation of lateral earth pressure does not match well with the observation values. In this project, the recorded active earth pressure is about 90% of the calculation value while the ratio of the recorded passive pressure and the calculated one is 1:2.6.
- The maximum horizontal movement of the retaining wall is 0.002 to 0.003 times the depth of the wall, which is greater than the empirical formula of 0.001H.

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Table 1 Soil strata and their main characteristics

Layer Numbers (Shanghai standardized)	Soil Names	Thickness (m)	Main Properties
1	Fill	1.20 to 1.70	
2	Silty Clay	1.40 to 2.40	C=17 kPa, ϕ=15.0, $N_{63.5}$=2, medium compressibility
3	Mucky silty clay	3.90 to 5.80	C=7 kPa, ϕ=29.0, $N_{63.5}$=1.8, medium compressibility
4	Mucky clay	9.00 to 10.2	C=14 kPa, ϕ=9.5, $N_{63.5}$=1, high compressibility
5	Silty Clay	5.80 to 6.80	C=17 kPa, ϕ=14.5, $N_{63.5}$=3.8, medium compressibility
6	Silty clay (hard)	3.80 to 5.40	C=47 kPa, ϕ=19.0, $N_{63.5}$=17, medium compressibility
7-1	Silt	6.40 to 8.30	C=1.5 kPa, ϕ=30.0, $N_{63.5}$=30, low to medium compressibility
7-2	Fine sand	24.7 to 26.6	C=0, ϕ=32.0, $N_{63.5}$>50, low to medium compressibility
8	Silt	2.65 to 4.00	$N_{63.5}$>47, medium compressibility
9-1	Medium sand	3.00 to 3.55	$N_{63.5}$>42
9-2	Fine sand	11.4 to 14.9	$N_{63.5}$>39, low to medium compressibility
9-3	Medium sand	7.20 to 11.1	$N_{63.5}$>45
12	Fine sand	> 10	$N_{63.5}$>50, low compressibility

Table 2 Settlement of the neighboring buildings

Points (x<8m)	S2	S3	S6	S7	S8	S9	S13	S18
settlement (mm)	-117.6	-197.7	-12.6	-127.1	-87.9	-31.9	-11.0	-102.2
Points (8<x<24m)	S1	S4	S5	S10	S12	S14	S19	S24
settlement (mm)	-66.3	-143.4	-134.8	-6.5	-1.6	-3.0	-37.5	-10.0
Points (x>24m)	S15	S16	S20	S25	S26	S31	S32	S38
settlement (mm)	+1.9	+2.2	-2.5	+1.9	+1.5	+0.4	+0.9	-1.1

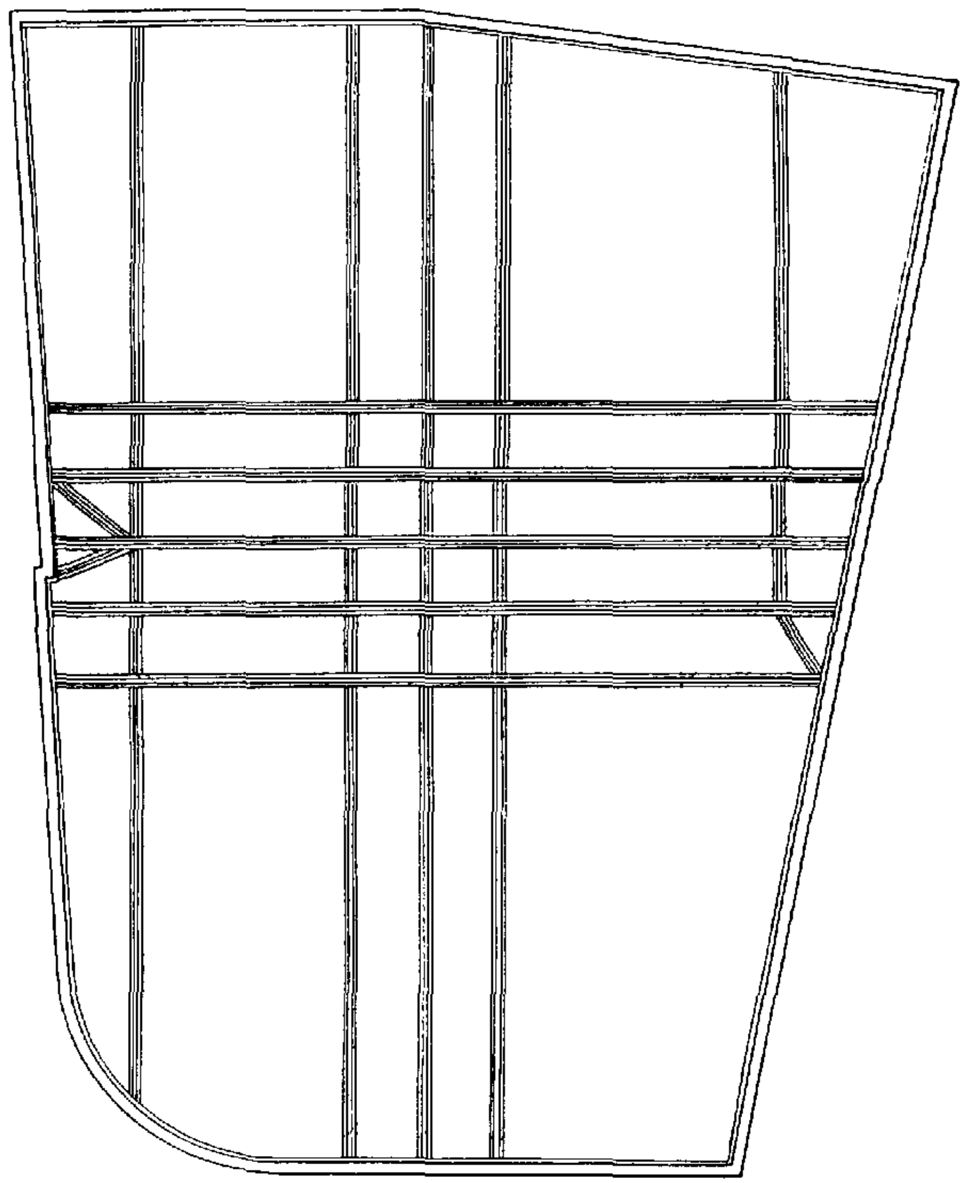

Fig. 1 Plane view of diaphragm wall and the steel support

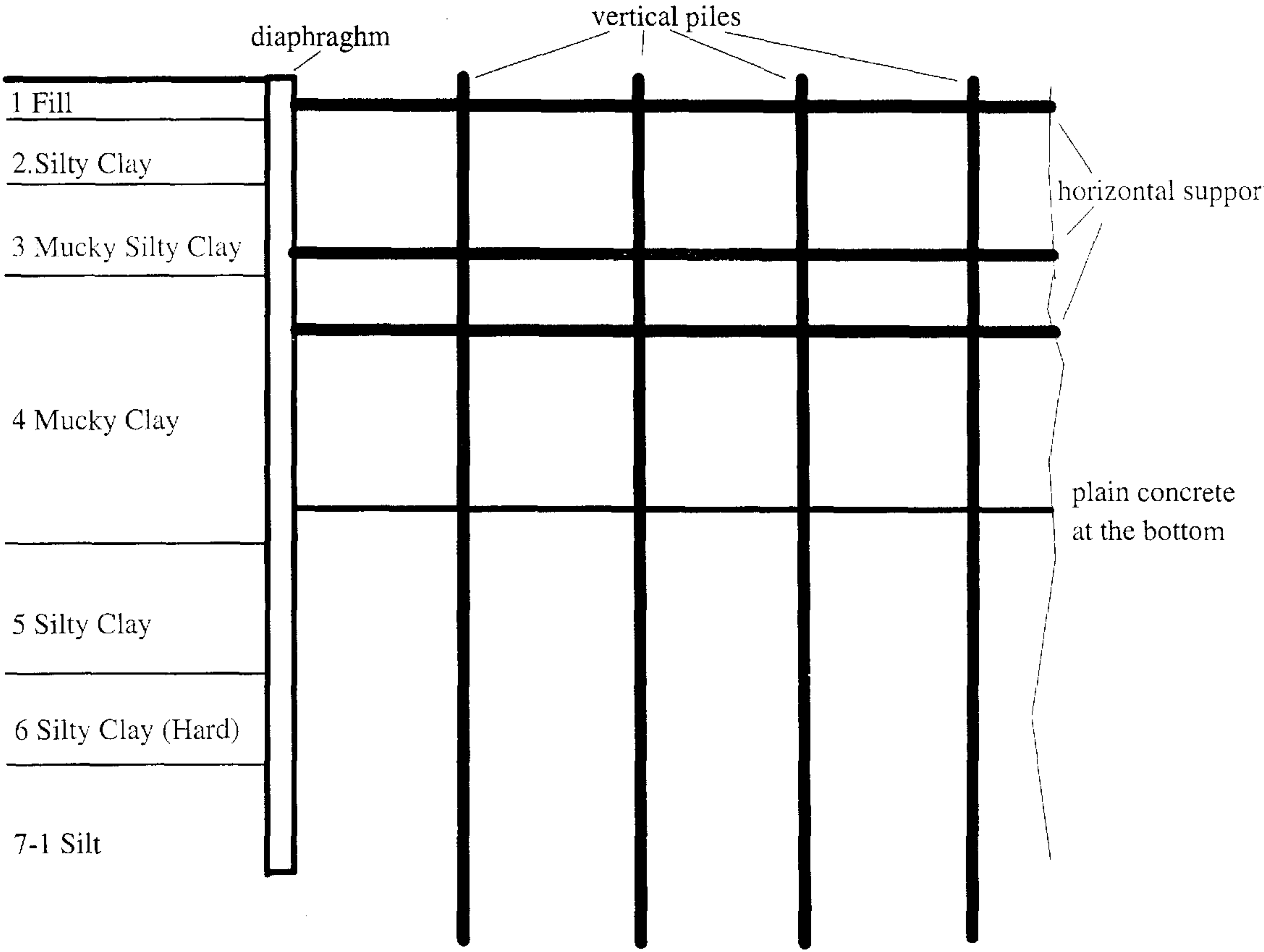

Fig. 2 Vertical profile of the retaining wall and the supports

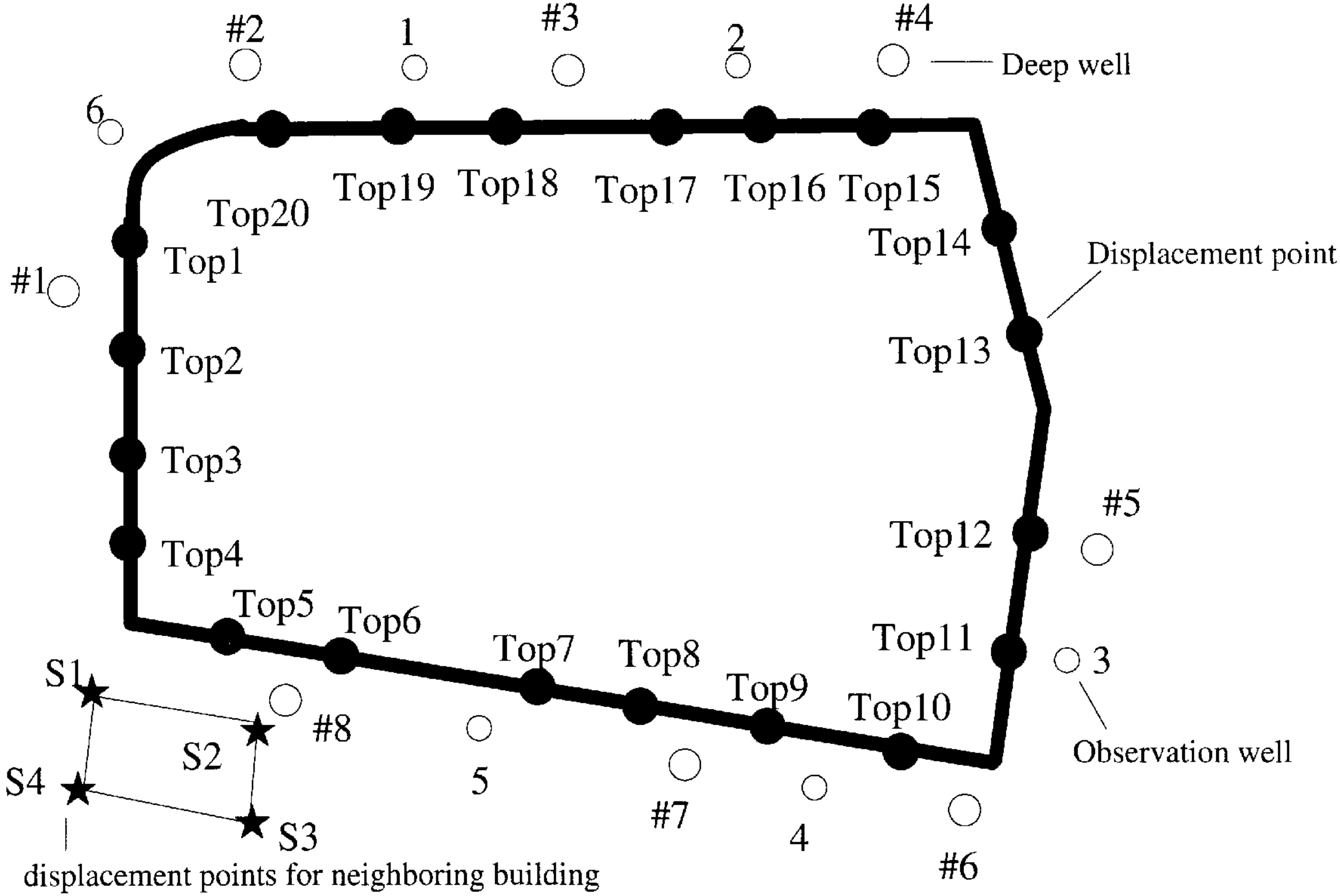

Fig. 3 Deep wells and displacement monitoring points

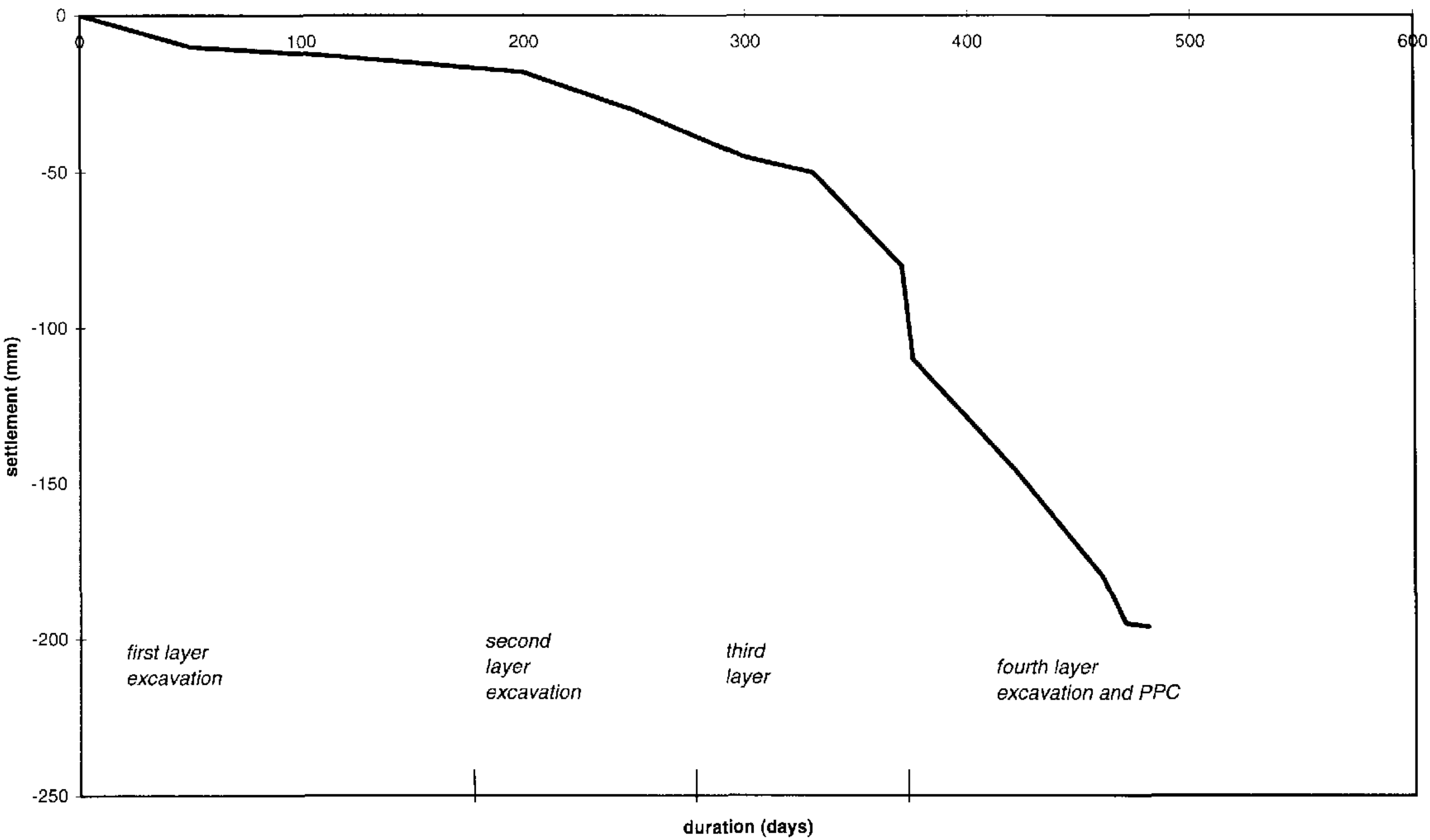

Fig. 4 Settlement ~ Time Curve of Point S3

Point	Displace-ment (mm)
Top 1	-47.7
Top 2	-41.5
Top 3	-48.3
Top 4	-49.3
Top 5	62.1
Top 6	36.3
Top 7	44.1
Top 8	55.7
Top 9	39.4
Top 10	7.4
Top 11	123.6
Top 12	16.8
Top 13	-6.8
Top 14	16.7
Top 15	-12.6
Top 16	-48.1
Top 17	-57.2
Top 18	-74.2
Top 19	-42.8
Top 20	-53.3

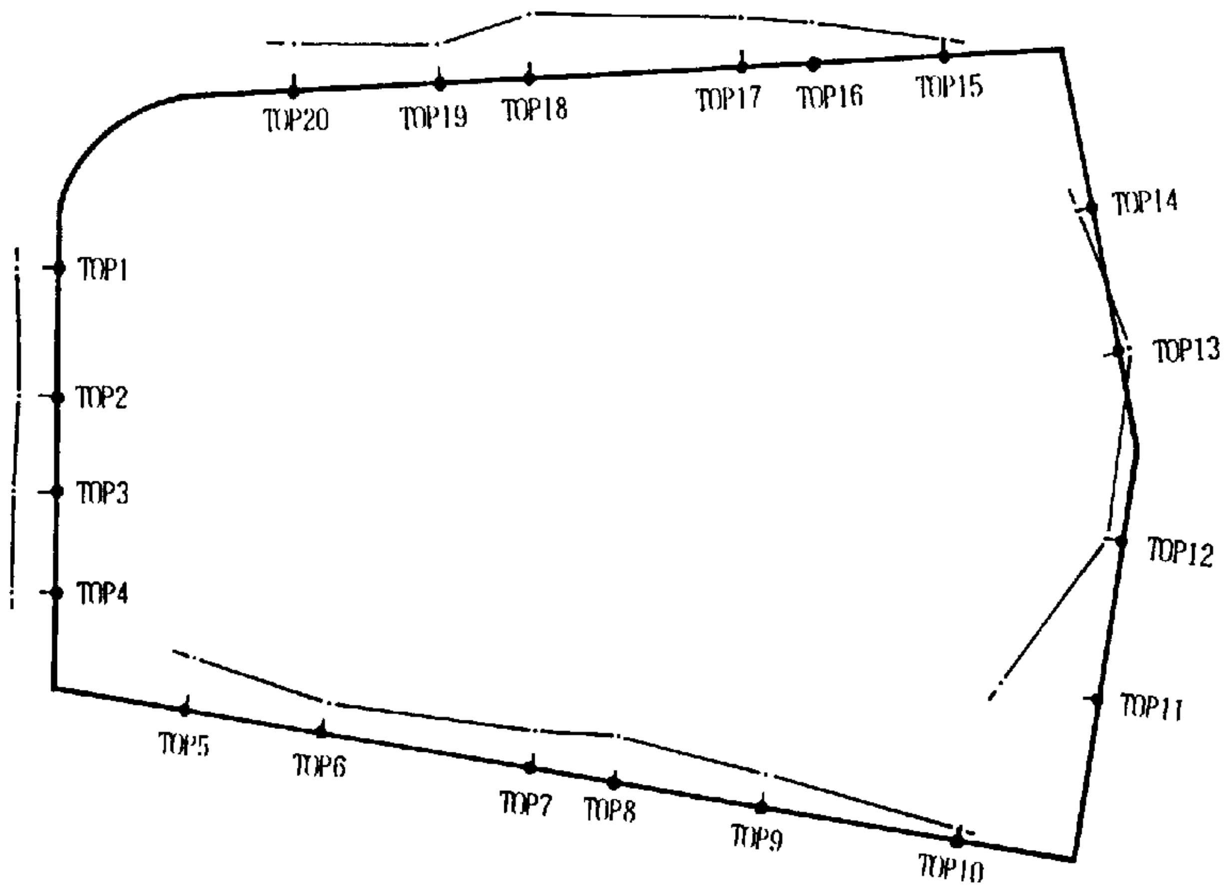

Fig. 5 Horizontal displacement of the retaining wall

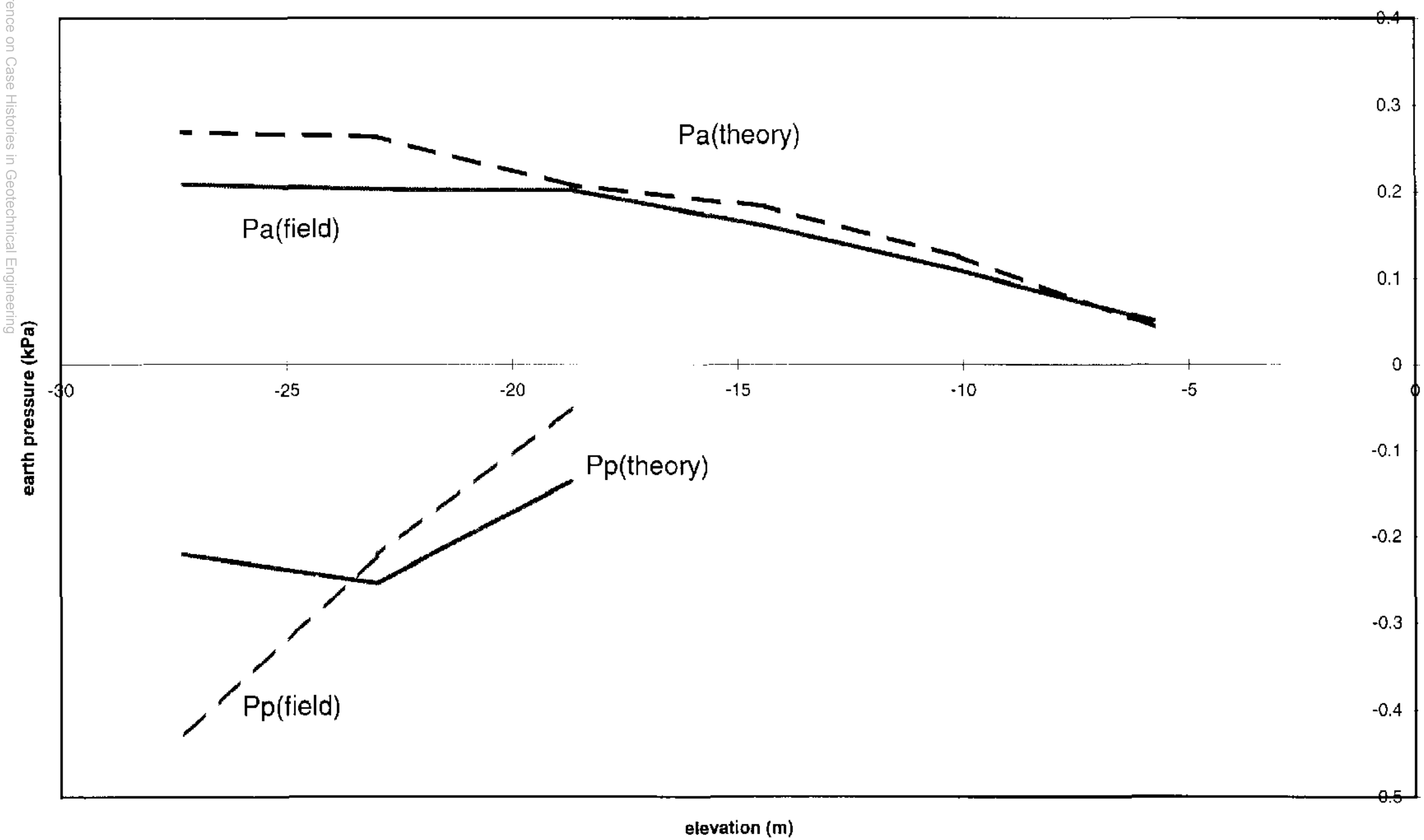

Fig. 6 Earth pressure after the final excavation