Analysis of the Influence of Foundation Pit Excavation on the Surrounding Surface Settlement and Retaining Structure

LingChao Shou, HeQuan Zhao, XiaoBo Sun, Jin Pang, Ting Bao, and LiFeng Wang

Abstract This paper analyzes the foundation pit of Gen Shan East Road through tunnels under the river. The results show: When digging to the bottom, the maximum horizontal displacement of the wall is located at 2 ~ 4 m above the bottom of the pit, and the maximum value is 0.57‰ ~ 0.64‰H. The surface subsidence is mainly of groove type. The maximum surface settlement is 0.107%H. The mean value of the maximum surface settlement is about 0.91 times the maximum horizontal displacement of the wall, and the maximum surface settlement is between 0.58 and 1.91 times the maximum horizontal displacement of the wall.

Keywords Foundation pit · Ground surface settlement · Horizontal displacement

1 Introduction

The soil unloading of foundation pit causes deformation of surrounding strata, which causes formation loss behind the retaining wall in a certain range and causes ground settlement. Large ground settlement will have a great impact on the surrounding structures and underground pipelines of the foundation pit, and even cause damage [4, 5]. Due to the great difference of stratum conditions in different regions, foundation pit engineering has strong regional characteristics [2]. Zhu et al. [6] collected the measured data of the surface subsidence outside the pit of 38 subway stations and studied the surface subsidence deformation law outside the pit of Changzhou subway

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stations from the perspective of statistical analysis. Guo [3] studied the influence of foundation pit excavation process on the deep horizontal displacement of retaining structure and the settlement of soil outside the pit. Cheng et al. [1] took a 30.2 m deep foundation pit project in Hangzhou as the research object, and analyzed the development and evolution rules of ground wall heave and flexural deformation, ground wall wall stress, column heave, supporting axial force, earth pressure, and surface settlement in the whole process of excavation of a 30.2 m deep foundation pit.

2   Project Summary

Take Gen Shan East Road crossing tunnel project as an example, The project located in Hangzhou city, includes a cross-river tunnel, a working well, and an open pit. This paper analyzes the influence of the excavation on the surrounding environment and the enclosure structure itself. The depth of the foundation pit is 15 ~ 21 m. Figure 1 shows the monitoring plan of the foundation pit, Fig. 2 shows the profile of the enclosure structure, and Table 1 shows the soil layer distribution.

3   Anaysis of Deformation Law of Underground Disphragm Wall

The deformation shape of the retaining structure of foundation pit is closely related to the form, stiffness and construction method of the retaining structure. In general, the lateral displacement of the enclosure structure is obtained by burying the inclined pipe in the reinforcement cage and collecting the data along with the foundation pit excavation. The deformation value at the end of excavation is counted to reflect the maximum horizontal displacement distribution of the foundation pit enclosure structure.

Figure 3a–f show the variation of wall horizontal displacement with the excavation condition. The figure shows: With the increase of excavation depth, the lateral deformation of wall gradually increases, and the depth of maximum deformation gradually moves down. The deformation shape of the wall changes from the initial top to the offset in the foundation pit into a "bulging" distribution with large middle and small ends. In the early stage of excavation, the maximum deformation value of the wall mainly occurs in the shallow position of the excavation depth, and the deformation amount is small, which is mainly because the excavation depth of the foundation pit is shallow, and the difference between the earth pressure inside and outside the pit is small. During the excavation to 5.8 m, the deformation of the foundation pit wall is large. The main reason is that the soil in the pit decreases and the difference between the earth pressure inside and outside the pit is formed. However,
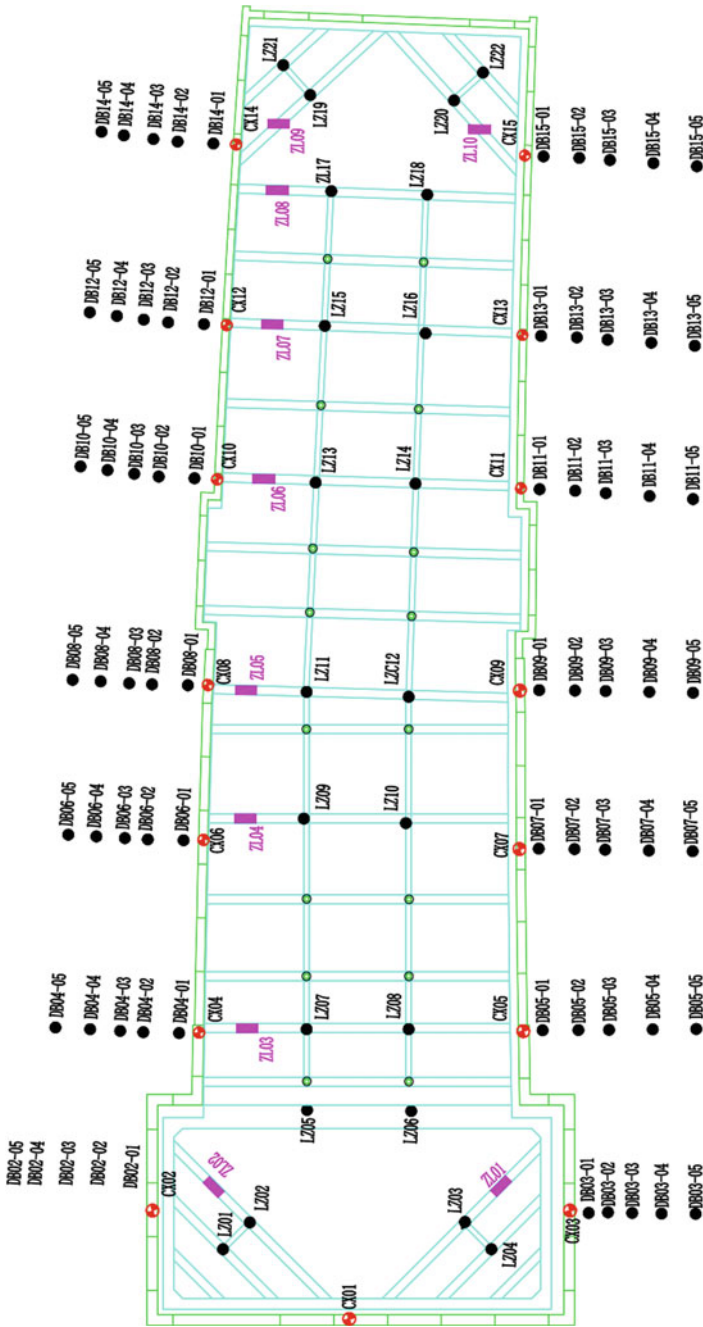
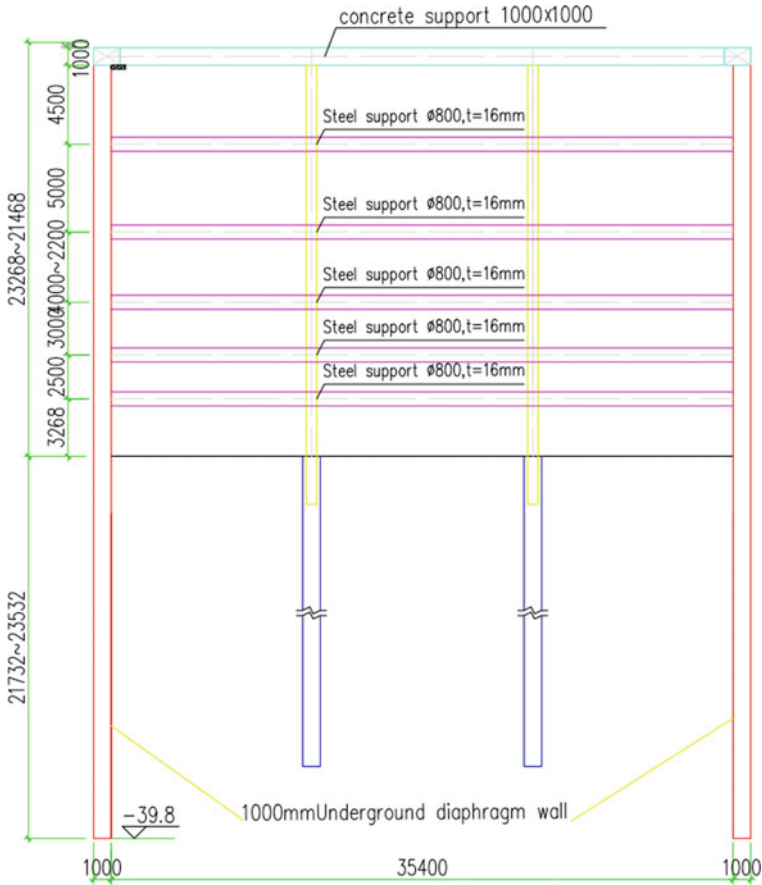**Fig. 1** The monitoring plan of the foundation pit

concrete support 1000x1000

Steel support ⌀800,t=16mm

Steel support ⌀800,t=16mm

Steel support ⌀800,t=16mm

Steel support ⌀800,t=16mm

Steel support ⌀800,t=16mm

−39.8

1000mmUnderground diaphragm wall

1000   35400   1000

1000 4500 5000 2000~3000 3000 2500 3268

23268~21468

21732~23532

Fig. 2 Section view of the envelope

the wall deformation mainly occurred during the excavation period from 5.8 to 12 m, mainly because of the large difference of earth pressure between inside and outside the pit. The monitoring data of the six typical monitoring sites are summarized as shown in Table 2. The maximum value of horizontal displacement at the end of excavation is 2 ~ 4 m above the bottom of the pit, and the maximum value is 9 ~ 11.2 mm (0.57‰ ~ 0.64‰H).

Figure 4 shows the relationship between the maximum horizontal displacement of the wall and the excavation depth obtained from the measurement points of the wall of Gendong Road working well. It can be seen from the figure that the horizontal displacement of the wall increases with the increase of the excavation depth, with a roughly linear distribution. The upper limit of the maximum horizontal displacement is 0.101%H, the lower limit is 0.042%H, and the average value is 0.069%H.

Figure 5 shows the relationship between the relative maximum horizontal displacement and the relative excavation depth. The relative maximum horizontal

Table 1 Soil layer distribution table

Serial number	Geotechnical name	Natural gravity	Characteristic value of foundation bearing capacity/kPa	Thickness/m	Cohesive/kPa	Internal friction angle/°
1	Miscellaneous fill	18	80	0.2 ~ 4.1	10	12
2	Sandy silt	19.7	110	2.9 ~ 18.9	6	26
3	Silty clay	17.6	90	22.9 ~ 41.8	12	15
4	clay	19.7	220	31.3 ~ 40.2	40	16
5	Conglomeratic clay	20.6	240	37.4 ~ 73.8	30	22
6	Fully weathered argillaceous siltstone	20.4	200	39.0 ~ 74.6	30	16

(a) CX15   (b) CX14

(c) CX11   (d) CX10

(e) CX5   (f) CX4
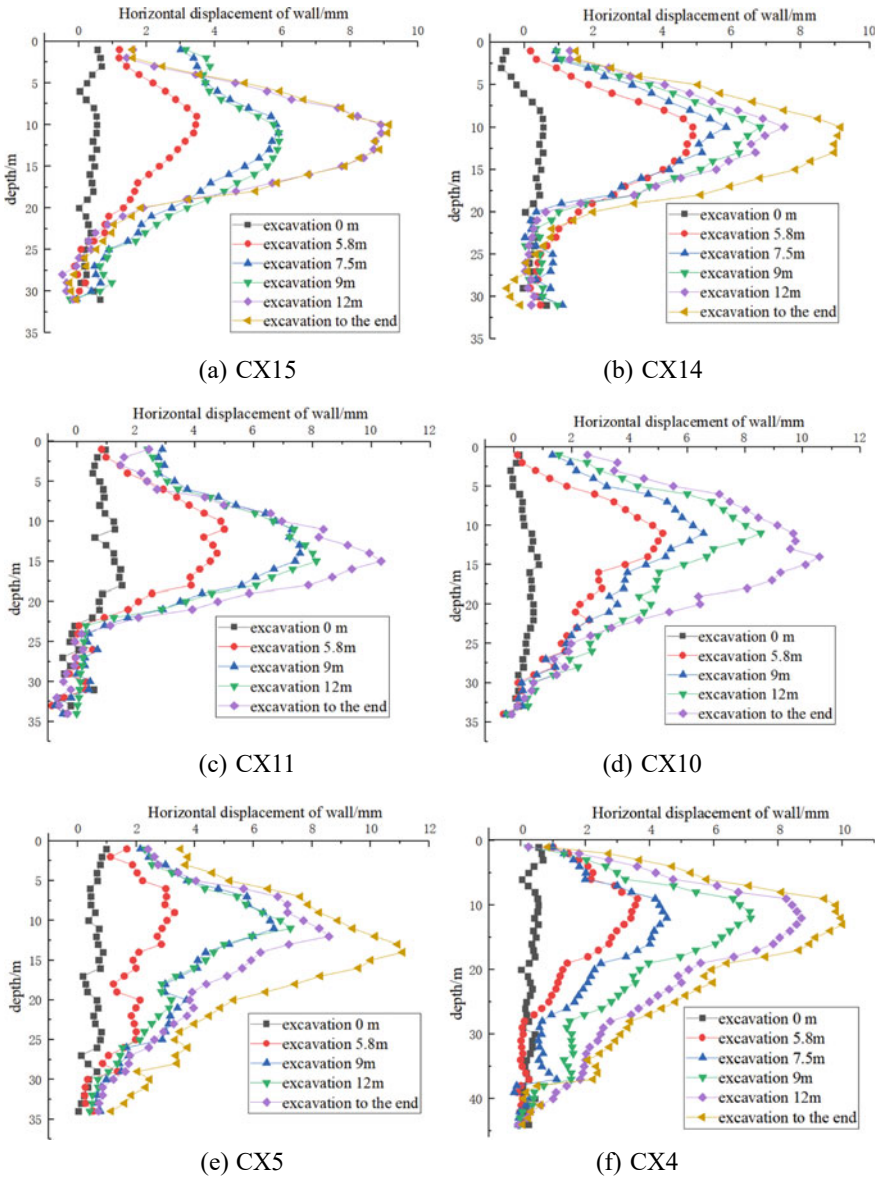
Fig. 3 Variation of wall horizontal displacement with excavation conditions

Table 2 Summary of monitoring sites

Serial number	Monitoring stations	Location	Max/mm	Relationship with excavation depth (‰H)
1	CX4	15 m above the surface (3 m above the bottom of the pit)	11	0.61
2	CX5	14.5 m above the surface (3.5 m above the bottom of the pit)	11.2	0.62
3	CX10	15.5 m above the surface (1.5 m above the bottom of the pit)	10.8	0.64
4	CX11	15 m above the surface (2 m above the bottom of the pit)	10.3	0.61
5	CX14	12 m above the surface (4 m above the bottom of the pit)	9.12	0.57
6	CX15	12 m above the surface (4 m above the bottom of the pit)	9.2	0.57

displacement has a linear relationship with the excavation depth, mainly because the excavation soil layer is soft soil layer such as silt and clay layer, and the distribution of the soil layer is relatively uniform.

Figure 6 shows the relationship between the maximum horizontal displacement depth and the excavation depth of the foundation pit. The figure shows: most scatter points are within a certain range, with the upper limit of 1.6 and lower limit of 0.67, and the average value is about 0.87H. This is close to Xu Zhonghua's conclusion that the maximum horizontal displacement depth of foundation pit retaining structure in Shanghai soft soil area is about 0.89H. However, there is a little error with the maximum horizontal displacement depth rule proposed by Ou. Among them, the rise of the maximum horizontal displacement depth is due to the better soil quality of the lower strata, which makes the overall stiffness of the enclosure structure increase. The overall stiffness of the project is larger than that of the soft soil area, and the excavation depth of the foundation pit with the maximum horizontal displacement depth of about 0.69 times is reasonable.
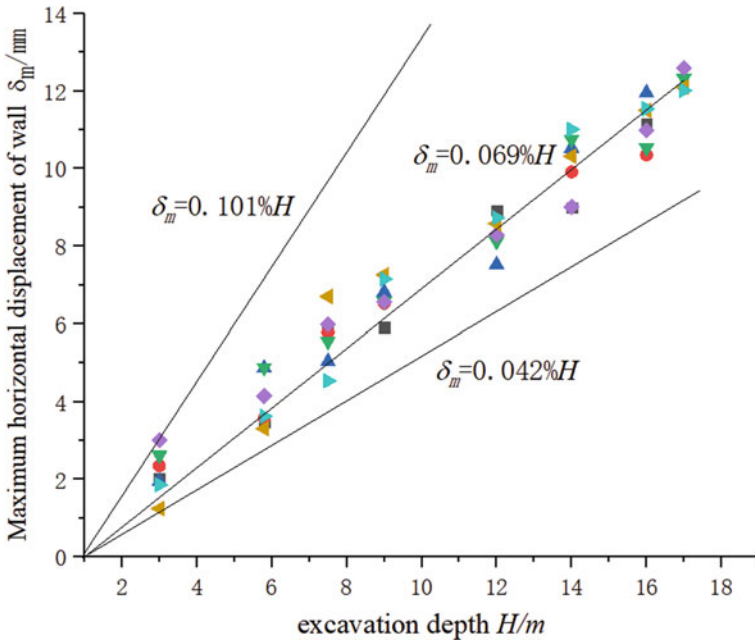
Fig. 4 Relationship between maximum horizontal displacement of wall and excavation depth
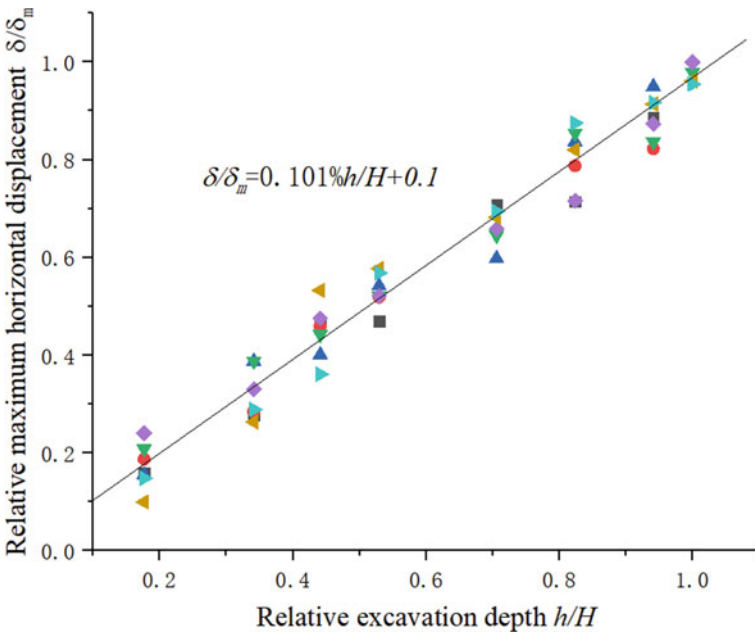

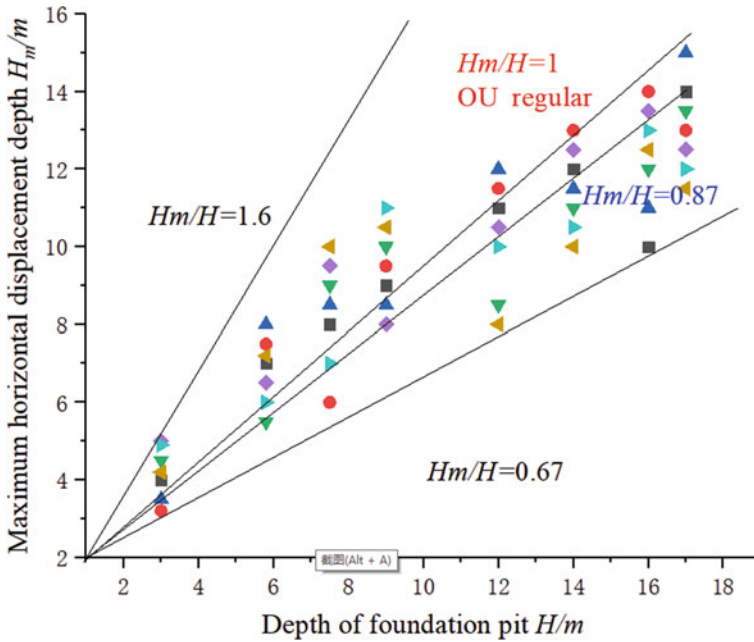**Fig. 5** Relationship between relative maximum horizontal displacement and relative excavation depth

Fig. 6 Relationship between maximum horizontal displacement depth and excavation depth of foundation pit

4   Surface Settlement Analysis

The excavation depth of the foundation pit is from 16 to 21.5 m, showing a downward slope. Fifteen surface settlement monitoring profiles are laid on both sides of the foundation pit, and the monitoring points vary from 5 to 7 according to the actual situation. Starting from the edge of the foundation pit, the spacing is 2 m, 4 m, 6 m, 8 m, 8 m, 10 m respectively. The spacing can be adjusted appropriately according to the actual situation on site.

Figure 7 shows the map of surface subsidence with working conditions for typical profiles of monitoring sites. The figure shows: at the beginning of excavation, the surface settlement is small. With the progress of excavation, the surface settlement is constantly increasing, and the surface settlement is stable and does not change after the demolition and support is completed. The maximum settlement value is basically located at 12.5 m outside the pit, and the maximum value at the section is 17 mm, 0.08%H (H is the excavation depth of 21.5 m). The surface settlement value of 50 m outside the foundation pit is within 2 mm. It shows that the influence of foundation pit excavation on this site is small and can be ignored. The surface subsidence is mainly of groove type.

Figure 8 shows the distribution of ground settlement behind the wall. The settlement range of area I, II, III of surface subsidence behind the wall proposed by Peck
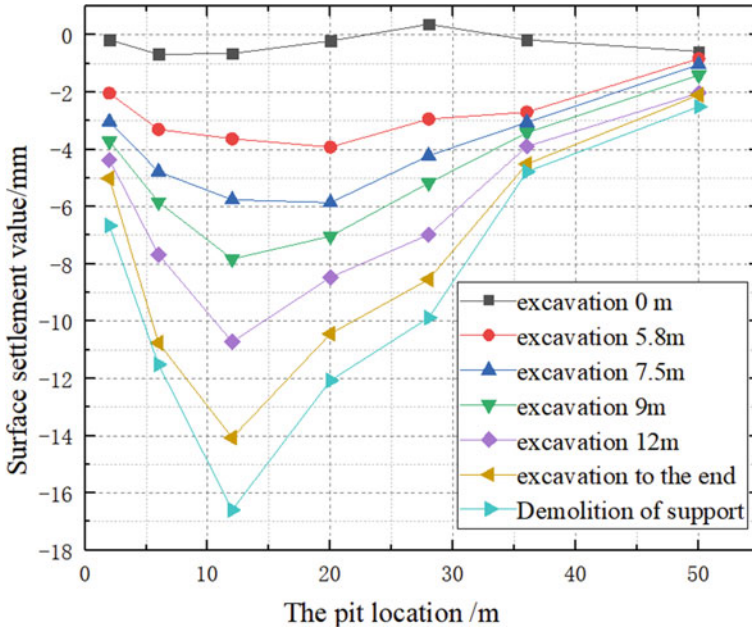
Fig. 7 Surface subsidence curve of typical section

is shown in the dashed area. According to the results obtained in this example, the settlement influence range in this area is 2H, and the monitoring underestimated the settlement influence range in this area. The settlement range of known settlement points is all distributed in area I, which is in good agreement with the soil conditions in this area. Figure 9 shows the envelope diagram of surface settlement. Most of the measurement points are distributed within the predicted range, but a small number of measurement points are outside it, which may be caused by external overload and nearby construction.

Figure 10 shows the relationship between the maximum surface settlement behind the wall and the excavation depth. With the increase of excavation depth, the maximum surface settlement also increases gradually. The surface settlement distribution outside the foundation pit can be basically divided into two parts. The first part is before the excavation of the foundation pit 12 m, when the mean value of the maximum surface settlement is about 0.075%h. The second part is between 12 m of excavation and the end of excavation, when the mean value of the maximum surface settlement is about 0.112%h. However, the upper limit of the maximum surface subsidence is 0.107%H.
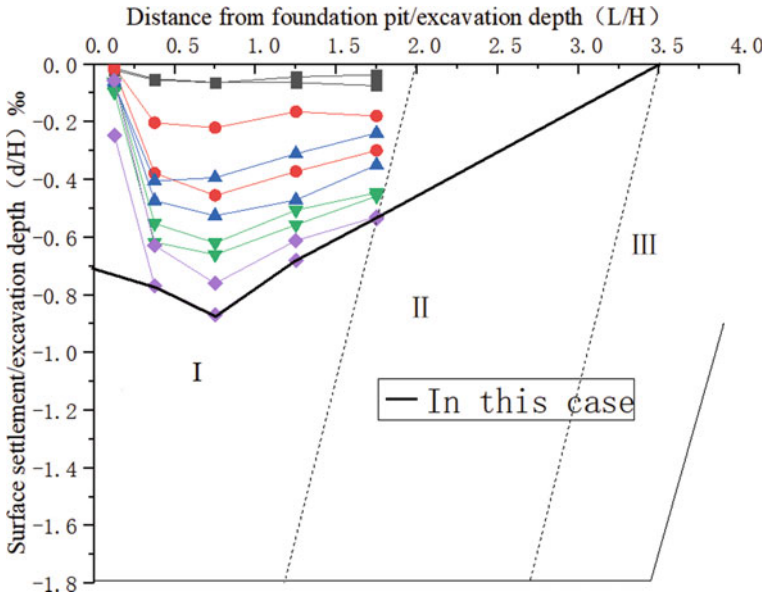
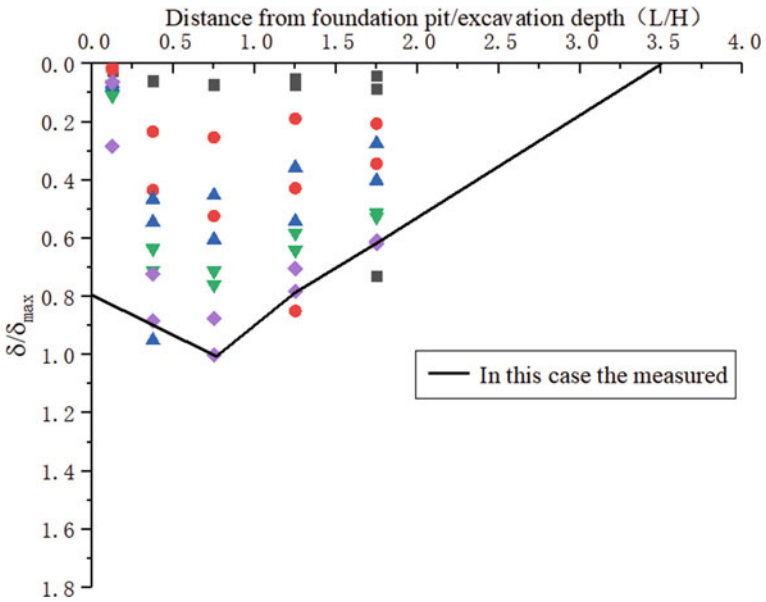Fig. 8   Dimensionless diagram of surface settlement curve behind foundation pit wall

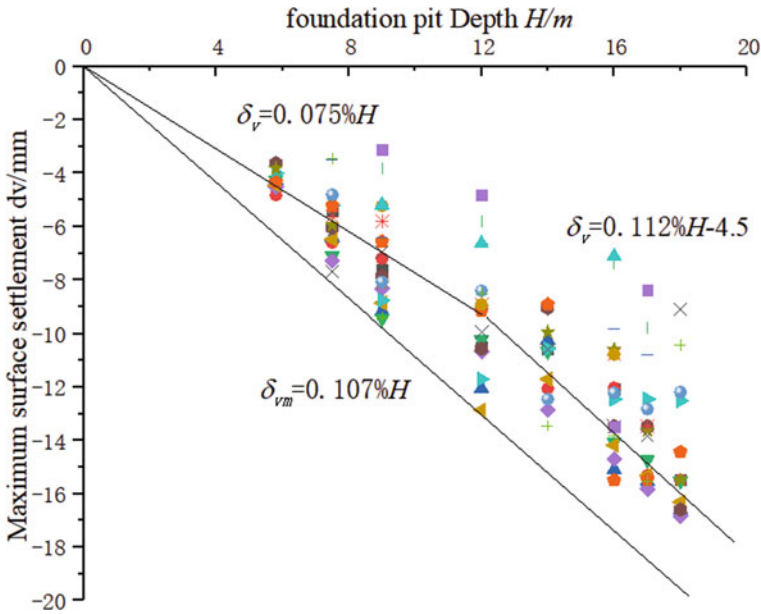Fig. 9   Surface settlement envelope diagram behind foundation pit wall

Fig. 10 Relationship between maximum surface settlement behind the wall and excavation depth

5 Relationship Between Surface Settlement Behind the Wall and Lateral Deformation of the Wall

Figure 11 shows the relationship between the maximum surface settlement and the maximum horizontal displacement of the wall in the process of foundation pit excavation. The figure shows: The mean value of the maximum surface settlement is about 0.91 times the maximum horizontal displacement of the wall. The maximum surface settlement is between 0.58 and 1.91 times the maximum horizontal displacement of the wall.

6 Conclusion

(1) At the end of excavation, the maximum horizontal displacement of the wall is located at 2 ~ 4 m above the bottom of the pit, and the maximum value is 0.57‰ ~ 0.64‰H. The horizontal displacement of the wall increased with the increase of the excavation depth, and the distribution was roughly linear. The upper limit of the maximum horizontal displacement was 0.101%H, the lower limit was 0.042%H, and the average value was 0.069%H. The maximum horizontal displacement depth of the wall is about 0.87H.
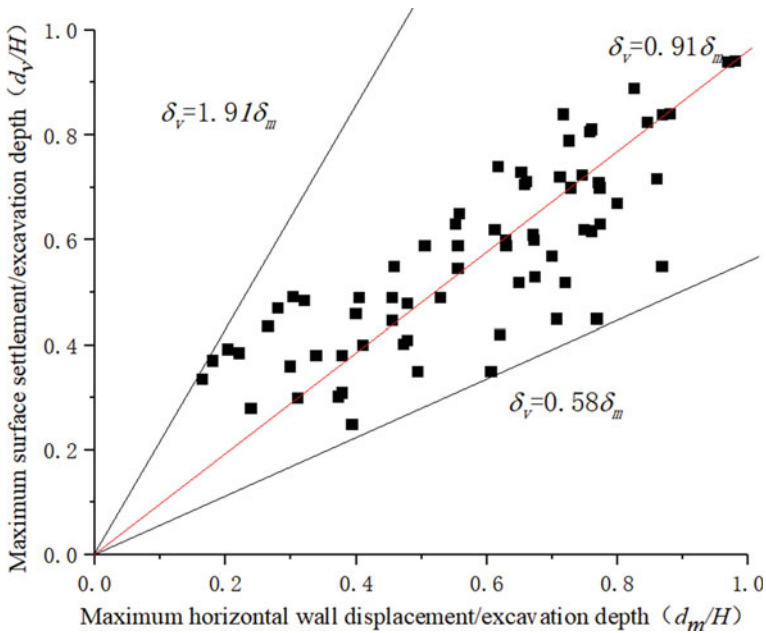
Fig. 11 Relationship between maximum surface settlement and maximum horizontal displacement of wall

(2) When the foundation pit is excavated to the end, the surface settlement is mainly in the form of groove. The influence range of settlement in this area is 2H, and the upper limit of the maximum surface settlement is 0.107%H.

(3) The mean value of the maximum surface settlement is about 0.91 times the maximum horizontal displacement of the wall, and the maximum surface settlement is between 0.58 and 1.91 times the maximum horizontal displacement of the wall.

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