

Excavation-caused extra deformation of existing masonry residence in soft soil region

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Abstract. Growing need for construction of infrastructures and buildings in fast urbanization process creates challenges of interaction between buildings under construction and adjacent existing buildings. This paper presents the mitigation of contradiction between two parties who are involved the interaction using civil engineering techniques. Through the in-depth analysis of the results of monitoring surveys and enhanced accuracy and reliability of surveys, a better understanding of the behavior of deformable buildings is achieved. Combination with the original construction documents, the two parties agree that both of them are responsible for building damages and a better understanding for the rehabilitation of the existing buildings is focused on. Two cases studies are used to demonstrate and describe the importance of better understanding of the behavior of existing buildings and their rehabilitations. The objective of this study is to insight into mechanisms of soil-structure interaction for buildings adjacent to deep excavations, which can result in a damage in existing masonry residence, and to take the optimized measures to make deep excavations safety and economic and adjacent buildings keep good serviceability in urban areas with soft soil conditions.

1. Instruction

It is common that some of the existing buildings affected by new construction with excavation nearby are not satisfied with serviceability required. With the high speed development of urbanization in China in the past three decades, the distances between new building constructions and infrastructures and their adjacent existing buildings become smaller and smaller inevitably. In addition, the evaluation of adverse effect caused by adjacent new construction, construction time, budget, and housing privatization do not match the speedy development of urbanization. These results in conflicts between new construction and adjacent existing buildings, especially in soft soil region.

This paper focuses on the elaboration of the interaction between a new construction and adjacent existing buildings from geotechnical engineering and structural engineering, geodesy monitoring, and evaluation methods. Then the effect of new construction on the existing buildings could be described



reasonably and quantitatively. The conflicts between the new construction's party and existing buildings' party are mitigated by the reliable evaluations. Then, the two parties would concentrate on rehabilitations or strengthening for the existing buildings if it is necessary rather than arguing with each other. Furthermore, the party of new constructions will take effective measures to compensate the party of existing buildings based on the field monitoring and analysis, as well as strategies for maintenance. Finally, the existing building serviceability is controlled within the allowable condition.

In soft soil region, for instance Shanghai, the conflict is more obvious than other regions due to geological reason. The physical and mechanical properties of typical stratum in Shanghai are listed in table 1.

Two case studies presented in this paper are from Shanghai residences in China. Both are in concrete raft foundation with 2.0 m embedded below ground surface. The residences are masonry structure with concrete ring beams on the floor elevations and concrete columns in the cross positions of brick walls. The floors are of precast hollow slabs, but concrete cast-in-place slabs for kitchens and washrooms. Both had severe cracks on the residence walls. The cracks are also on the ground surface around them. The crack widths on bearing brick walls and self-weighted walls are over limitation (GB/T 50344-2004, DG/TJ 108-79-2008, and DG/TJ 08-804-2005) in diagonal direction, irregular cracks exhibit on the ceramic tiles attached on the decorated layer in kitchen and wash-room, as well as excessive deformations appear on the frame of windows and doors.

Table 1. Physical and mechanical properties of typical stratum in Shanghai

Strata	Name of soils	Thickness	Water content	Bulk density	Void ratio	Permeability coefficient		CU test	
		m	%	kN/m ³		k_h cm/s	k_v cm/s	C kPa	ϕ °
①	Fill	0.9-2.0	-	-	-			11	17
②	silty clay	1.5-2.2	35.3	18.5	1.00	5.11E-05		17.0	20.8
③	Very soft silty	3.6-4.2	39.6	18.1	1.11	1.77E-04	2.81E-06	11.5	22.0
④	Very soft clay	7.2-9.7	49.0	17.3	1.37	1.64E-06	2.47E-07	14.0	13.5
⑤	Silty clay	3.4-8.6	34.4	18.5	0.98	1.33E-07	2.49E-05	13.0	20.0
⑥	Silty clay	3.2-5.3	23.0	20.1	0.67			51.0	21.0
⑦	Sandy with clay	6.9-7.3	31.2	18.6	0.91			4.29	32.7

2. Field monitoring

2.1 Residence 1

The residence 1 (photo.1) built in 1995 is located in the center of Shanghai in China (latitude 31° 16' 51.58", longitude 121° 25' 24.22"). The minimum net distance away from the new construction is 10 m. The maximum depth of excavation of new construction is 9.8 m. The new construction began from December, 2014. The filed monitoring conducted by Tongji University started from January 22, 2016 and ended on April 15, 2016. The measure points are shown in figure 1.



Photo 1. Layout of residence 1 (from google earth, July 2016)

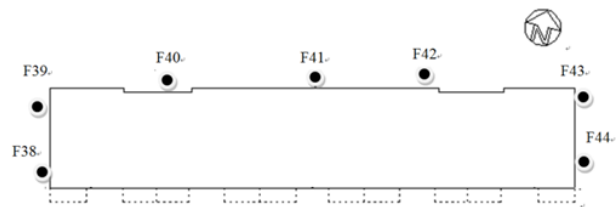


Figure 1. Layout of measure points

The points of the connecting transverse are easy to design when we follow the previous reference point about 50 m in south east of the residence. The measurement points follow the previous monitoring team who conducted settlement measurement from the end of December, 2014 to January 19, 2016. The settlements in different period (figure 2) are listed in table 2.

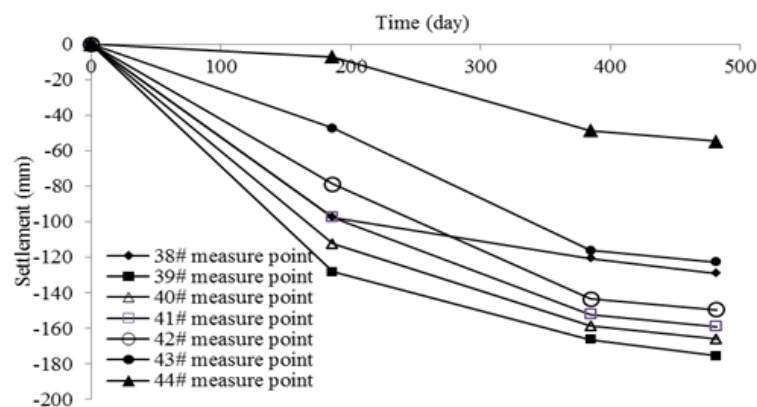


Figure 2. Excavation-caused settlement; time 0 denotes May December 20,2014.

Table 2. Accumulated settlement in different periods since new construction beginning (mm)

	MP	F38	F39	F40	F41	F42	F43	F44
S1	P1	-97.6	-128.3	-112.4	-97.6	-79.0	-47.4	-7.3
	P2	-120.7	-166.2	-158.6	-152.2	-143.6	-116.3	-48.7
S2	P3	-8.4	-9.3	-7.5	-6.7	-6.0	-6.5	-5.9
TS	P4	-129.1	-175.5	-166.1	-158.9	-149.6	-122.8	-54.6

Note: MP denotes Measurement Points; S presents Settlement; S1 and S2 means Settlement from the previous monitoring team and Settlement from Tongji University, respectively; TS for Total Settlement; P stands for measurement period; P1, P2, P3, and P4 denotes the period of Dec.,2014-June 24,2015, Dec. 2014-Jan. 19,2016, Jan.22,2016-April 15,2016, and Dec. 2014- April 15,2016.

It is noted that the Tongji University checked the previous system before monitoring to ensure that the results are reliable. Assume the residence is rigid body despite of moment deformation, combined with settlement data in different periods, we can deduce the initial residence inclination before new construction begins, during of excavation of adjacent new buildings, and after excavation. The analysis results are listed in table 3.

Consider that the inclination of residence 1 is approaching the criteria of 10 % (JGJ 125-99,2004), we calibrated the Total station (RTS112SR5L) made by Germany and monitored 10 lines. Each line had been monitored three times. Each time we read three coordinates. This technical measure can migrate the errors

from measurement system and limited data. The residence inclination on April 15, 2016 is shown in figure 3.

Table 3. The residence inclination in different periods (‰)

Position	Initial inclination before new construction beginning	Dec.,2014 - Feb. ,2016	Feb. 2016 - April 2016
North west	1.8	7.60	1.57
North east	5.2	4.39	2.82

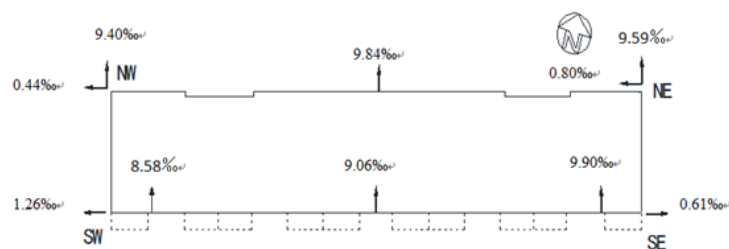


Figure 3. Residence inclination in representative positions

2.2 Residence 2

The residence 2 (photo 2) is located in the south of Shanghai in China (latitude 31° 12' 18.34", longitude 121° 22' 50.37"). They were built in 1993 and 1994. The new construction (tunnel) began from November, 2003. The filed monitoring conducted by Tongji University started from May 24, 2006 and ended on July 28, 2006. The measure points are shown in figure 4. The size of the building and initial condition is listed in table 4. The minimum net distance away from the new construction is 9 m. The maximum depth of excavation of new construction is 6 m. The settlements during and after tunneling construction are shown in figure 5.



Photo 2. Layout of residence 2

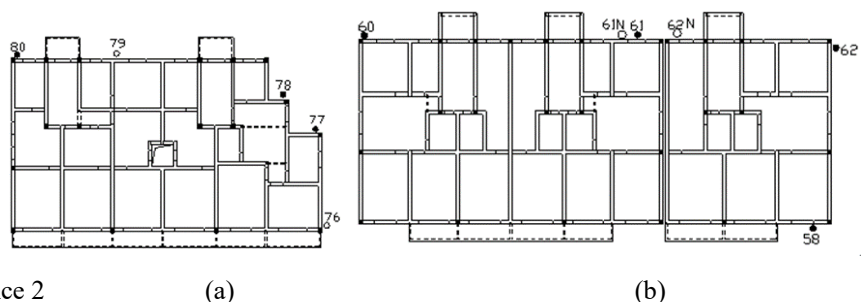


Figure 4. Layout of measurement points: (a) 1# residence; (b) 4# residence

Table 4. Size and initial condition of the buildings

No. of residence	1#	2#	3#	4#	5#	6#
Height of story / m	2.8	2.8	2.8	2.8	2.8	2.8
Width / m	12.3	12.3	12.3	12.3	12.3	12.3
Length / m	22.0	40.2	53.7	31.5	43.0	34.0
Initial condition	Note 1	Normal	Normal	Normal	Normal	Normal

Note 1: 60 square meters located on the dark creek processed. Note 2: It includes two parts which are not built at the same time. The settlement joint between two parts is 280 mm width.

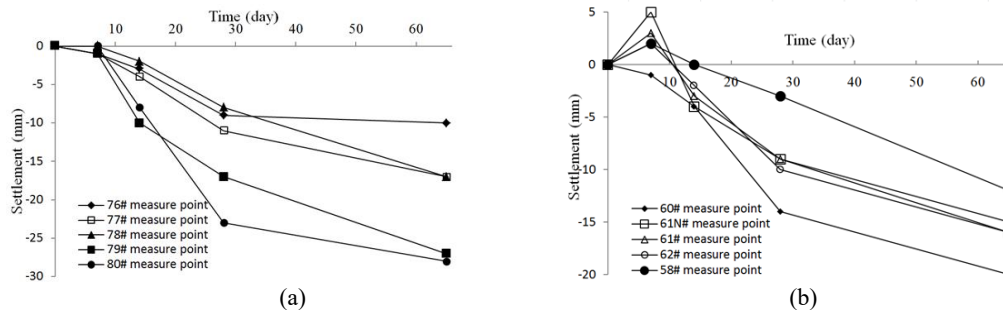


Figure 5. Settlement caused by new construction nearby: (a) 1# of residence 2; (b) 4# of residence 2

Combining the deformation measurements from August to September, 1994, October, 2004 to February, 2006, and May to July, 2006 together, the residence inclinations are monitored (Tang, 2010), part of the results is listed in table 5.

Table 5. The residence inclination in different periods (%)

No. of residence	Before new construction beginning	Duration of new construction ^{a,b}	July 28, 2006
1# West	5.00	3.76	10.238(11.720)
4# West	5.00	2.66	7.705(7.590)

^a The values in brackets are from settlement monitoring data. ^b Monitoring duration of new construction from Oct., 2014 to Feb., 2006

3. Result analysis and strategies for rehabilitation

3.1 Result Analysis

Residence 1 and 1# of residence 2 have 5‰ initial inclinations (table 5). Compared with other monitored buildings, they have more increments of inclination. Maximum inclination rates are 2.82‰ and 0.19‰, respectively.

Maximum settlement rates during two months filed monitoring by Tongji University are 0.090 and 0.043 mm/d, respectively. From the slope of settlement rate, they are not stable. Tang and Zhao (2012) found that the soft layer under rafts of residences is not convergent due to constant slope of deformation based on laboratory Triaxial tests. Assume the residence has 10‰ inclination, the maximum allowable inclination (JGJ 125-99), residence 1 has 100 mm differential settlement northward and residence 2 has 210 mm westward. And according to elastic theory, we can deduce the differential stress on the rafts according to equation (1).

$$S = \frac{P}{E} H \quad (1)$$

Where S is settlement, P is average stress on the raft based on the loads of superstructure and self-weight of foundation, usually take 100 kPa, E is soil elastic modulus, and H is thickness of compressive layers.

Assume the residences have 150 mm average settlements (based on local experiences) after two decades service, then the settlements for residences 1 and 2 after adjacent new constructions are 250 mm and 360 mm, respectively. $S_0 = 150$ mm, $S_1 = 250$ mm for residence 1, $S_1 = 360$ mm for residence 2, $P_0 = 100$ kPa.

$S_0 = \frac{P_0}{E} H, S_1 = \frac{P_1}{E} H$, then $\frac{S_0}{S_1} = \frac{150}{250} = \frac{P_0}{P_1} = \frac{100}{P_1}$. Thus, $P_1 = 240$ kPa. Similarly, we can get $P_1 = 240$ kPa for residence 2. Therefore, estimated stress increments due to inclinations are 67 kPa and 140 kPa for residences 1 and 2, respectively. These stress increments will lead to more extra differential settlements and inclinations.

On the basis of the settlement rate, inclination rate vs. initial condition, as well as the deformation caused by different period conducted by scientific analysis, we can better understand the results of monitoring surveys and two parties realize their responsibilities for the present condition of the residences. Then both parties will concentrate on how to improve the serviceability of the residences.

We also employed the finite element software to evaluate the bearing capacity and seismic performance of the residences (the process is omitted here). The result is almost satisfied with the requirements (GB 50009-2012, GB 50011-2010, and GB 50007-2011).

3.2 Strategies for Rehabilitation

There are various measures to avoid existing buildings adjacent new constructions from excessive deformation. For instance, underpin under existing shallow foundations, install diaphragms around existing foundation to isolate existing buildings and new constructions, mitigate excavation deformation itself, and mitigate existing building settlements by effective methods.

4. Conclusion

New construction should make sure that adjacent existing building to be in normal service situation by various permanent or temporary measures although it is not difficult to achieve. In soft soil region, multi-story brick masonry buildings with shallow foundations are very sensitive to adjacent new constructions which are with deep foundations accompany with deep excavations. Two case studies show that extra 5~7% inclination happens easily if they have initial defects, such as initial inclination. Evaluation of extra deformation and structure safety should be done before the new construction begins. It is recommended to protect existing buildings or mitigate deformation of excavation of new construction if the evaluation exhibits that the existing building is vulnerable.

It is important to understand the existing building behavior to assure field monitoring accuracy, reasonable data process.

Acknowledgments

Thanks to Professor Zhou Deyi Dr. Feng Jintao who monitored in the field of residence 1 and residence 2, respectively. Thanks to Professor Edward Kujawski who helped to analyze data measured in the field of residence 2. Finally, thanks to the financial support from the National Natural Science Foundation of China (NSFC grant No.50818153 and No. 51278359).

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