The use of piling and underpinning for house protection in deep excavations: case studies from Taipei, Taiwan

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ABSTRACT: The space in metropolitan area in Taipei is very limited associated with the increasing number of population recently, so the use of deep excavations is expected to be a solution and has drawn lots of concerns from residents in Taipei. Since the ground in Taipei is soft and it is common to see many buildings surrounded the construction areas, several measures have been taken to reduce the settlement of adjacent buildings led by the excavations to protect the structures. Among these, piling outside the excavation as well as the underpinning of the buildings were often carried out in Taipei. In this paper, several complete case histories of the excavations in Taipei using piling and underpinning will be carefully studied and the observed ground and building behaviour will be explored also. In comparison with excavation cases in the United Kingdom and Japan, the feasibility and advantage for the application of piling and underpinning of the buildings in the deep excavations will be discussed.

1 INTRODUCTION

Owing to the limitation of space in metropolitan area in Taipei, deep excavation has to be used for both public infrastructure construction and private sector. However, some buildings are located very close to the excavation and the ground is soft there. Based on recent experience in Taipei, Moh and Chin (1993) illustrated several protection measures might be considered, such as underpinning, compacting grouting, cut-off-piling wall and strengthen structure, as shown in Figure 1. Among them, underpinning and cut-off-piling wall might be most common to be utilised in Taipei. In this paper, completely case histories of two excavations having underpinning and piling protection of adjacent structures on Nankang Line of phase 1 of Taipei Rapid Transit System (TRTS) are described and their effectiveness are explored and discussed as well.

2 THE SITE

Yung- Tsung (BL14) station on Nankang Line of TRTS were located on Chung- Hsiao East Road in Taipei City, near Hsinyi project township. The excavation depth is 16.7m bgl and a cross section of the excavation at BL14 station was shown in Figure 2. 1.2m thick, 38m deep diaphragm walls were installed to retain the earth due to the excavation. A 21.1m excavation was dug beneath the building “Joint Development Building” next to BL14 station for the exit of underground station (JDB- Exit A) and a cross section was presented in Figure 3. JDB- Exit A was constructed bottom-up but BL14 station was built top-down and its central concourse level slab was constructed after the installation of the bottom slab. The major soil strata here are the Sung-Shan Formation consisting of very thick clay and silt above gravel material. The soil profile at the sites is presented in Figure 2 and Figure 3. The weak sandstone was found below the gravel layer at these two sites. The undrained shear strength at the base of the final excavation was around 50 to 70 kPa. The angle of shear resistance determined by consolidated undrained triaxial test has been measured as 30°-34° for the Sung- Shan Formation.

3 THE USE OF PILING AND UNDERPINNING FOR DEEP EXCAVATIONS IN TAIPEI

Moh and Associates Inc. (1998 and 2000a) reported that some buildings are several meters far from the excavation at BL14 station and JDB, so steel props were used here to support these surrounding buildings. The installation of all underpin props was carried out after the completion of the 1st stage shallow excavation at the south end at the BL14 station. Also, prestress was added to these props for the underpinning at the JDB- Exit A to stop more foundation settlement of a 4-floor house, C1043, as shown in Figure 4. Further, at JDB- Exit A, to limit the damage of building C1043, which tilted severely before the start of main excavation, an extra series of contiguous piles was driven into the ground between the diaphragm wall at JDB- Exit A and this house.

4 OBSERVATION

Boscardin and Cording (1989) illustrated the building response related to the excavation-induced settlement. They showed that horizontal strain and distortion caused by the excavation might lead the damage of the structure. The building settlement resulting from the excavation was observed at BL14 station and JDB- Exit A sites. The observed building settlement obtained from station SB36- SB38 at the north end of the BL14 station was 20mm before the start of main excavation and it was raised up to 30mm at the completion of the excavation, as shown in Figure 5. In contrast, the building settlement at the south end (SB137- SB141) is much larger than that at the north. The maximum building settlement was around 20- 25mm before the main excavation and continued to increase to 80- 110mm at the end of the excavation, as presented in Figure 6. The basement of a 12- floor resident building near southwest corner of BL14 station was excavated at almost the same time as the excavation at the BL14 station and it was presumed it is the reason to lead more settlement at the south. Also, the buildings at the north end of BL14 station were supported by raft foundations and this might reduce the maximum building settlement. The measurement of building settlement of some buildings near JDB- Exit A site is presented in Figure 7. The observed building settlement reached 20- 35mm after the wall installation and continued to increase to 60-90mm at the end of the excavation and no underpinning was used here.

5 DISCUSSION

As illustrated above, the underpinning and protective piling were utilised at the BL14 station and JDB- Exit A sites. The efficiency of these protection measures is assessed in the following sections.

5.1 The use of underpinning to support buildings adjacent to excavations

Moh and Associates Inc. (1998) reported that up to 40mm building settlement occurred during wall installation and the 1st stage shallow excavation at BL14 station in attempt to prevent the development of excessive movements at later stages. Underpinning was carried out to support the nearby buildings. Despite these measures, the observations of the settlement points SB137 and SB141 at the south end of the BL14 station show that the buildings continued to settle markedly after the installation of the underpinning, and reached about 80- 110mm by the end of the excavation, as shown in Figure 6. Clearly, the underpinning here was insufficient to prevent significant building movement. Limited amounts of steel- props underpinning were installed at the top of the wall to support the buildings nearby and the structural loads of the adjacent buildings were transferred to the diaphragm wall only. In this way, the load can not be sufficiently passed to the hard soil strata and would not be able to reduce the ground movement induced by the excavation. Figure 8 presents the building settlement observed from the station SB122 and SB123 at the building C1043, which is close to the excavation of JDB-Exit A site. The underpinning was installed at the top of the wall to support the building C1043 prior to the starting of main excavation at JDB- Exit A. The building C1043 continued to settlement to 50-70mm at the end of the excavation and there is only a limited difference with the observation of building settlement obtained from other surrounding buildings at JDB- Exit A without the underpinning. Figure 9 shows the observation of building settlement from a close underground station, BL12, having similar excavation depth and width as well as ground and adjacent foundation conditions but the underpinning was not utilised here. It was seen that the maximum building settlement of some close structures continued to increase to 120mm, which is approximately the same with the one observed at BL14. Indeed, a consistent conclusion about the function of the underpinning was established by the observation of building settlement of the C1043 house at JDB- Exit A and at BL14 and BL12 stations. As the tilt of building is also considered, Figure 10 shows the tilt of building C1043 and its maximum tilt reached 3×10^{-3} at the end of monitoring. Accompanying the observation at BL12 station, Moh and Associates Inc. (1995) reported the maximum tilt of surrounding structures is 2×10^{-3} to 4×10^{-3}. It indicated the underpinning at JDB- Exit A site may not limit the building rotation induced by the excavation. The observations in Taipei contrast sharply with behaviour observed during the construction of a new underground station beneath the Circle line and District lines at Westminster station in London (Stone and Crawley, 1999). The underpinning was carried out here to take the load of existing station structure to the deeper harder soil strata before the start of excavation. The load of the station structure was supported by a 1.39m deep slab flanked by 3.315m ×1.5m edge beams beneath and was transferred to the deeper ground by a few 55m deep piles in the diameter of 3m or 1.8m. Further, a new subway tunnel was planned to excavate beneath a 33m wide, 270m long, 3-floor underground shopping mall and an existent tunnel in Nagoya City, Japan (Iwasaki et al., 1994). For supporting the structures of the shopping mall and subway tunnel during the excavation, some 15m long, 1m in diameter case-in-place concrete piles were constructed below the structures to transfer the loads to a layer of stiff clay in the ground. Associated with the field observation, the maximum settlements of the structures reach 2-4mm at the end of the excavation. Considering the cases in both of London and Nagoya City, underpinning piles were installed into the stiffer soil strata to transfer the load of the upper structure effectively and they were contrary to the observation from the BL14 station and JDB- Exit A sites. In this sense, unless the load of the adjacent buildings was sufficiently transferred to the stiffer ground, the underpinning technology would not be able to decrease the ground displacement induced by the excavation.

5.2 Piling for the house protection

Woo (1996) suggested that the piling outside the excavation may be able to form a cut- off wall to reduce the lateral pressure as well as the lateral movement caused by the excavation. Therefore, the piling technology was carried out at two different sites: JDB Exit- A and Mingshen Water tank (Moh and Associates Inc., 2000b). At the site of the Mingshen water tank, the piling at the north end of the excavation was installed for the protection of adjacent buildings. A row of 45cm diameter jet grouting piles was installed from ground level to the depth of 21m bgl before the starting of the excavation. However, the tip of the jet grouting piles did not reach the level of rock bed or stiff soil. Hence, the field monitoring shows it was not able to reduce the lateral deflection significantly. As the jet grouting piles installed before the main excavation could not reduce the lateral movement of the wall caused by the main excavation, an extra row of 60cm diameter deep mixing cement piles from ground level to the depth of 14m bgl was installed between the previous jet grouting piles and residential buildings during the main excavation. However, the deep mixing cement piles could not reduce the lateral movement of the wall either. Apart from the piling at Mingshen water tank, to protect the 4- floor house C1043 at the northeast corner of the excavation of the JDB- Exit A, a row of 20m deep, 40cm diameter contiguous piles was installed to reduce the ground movement caused by the excavation. However, accompanied with field observation, the ground movement did not reduce at all after the installation of these piles. The tip of these contiguous piles could not reach the hard soil strata at the site of JDB- Exit A and it was presumed to be the reason that the ground movement could not be reduced effectively.

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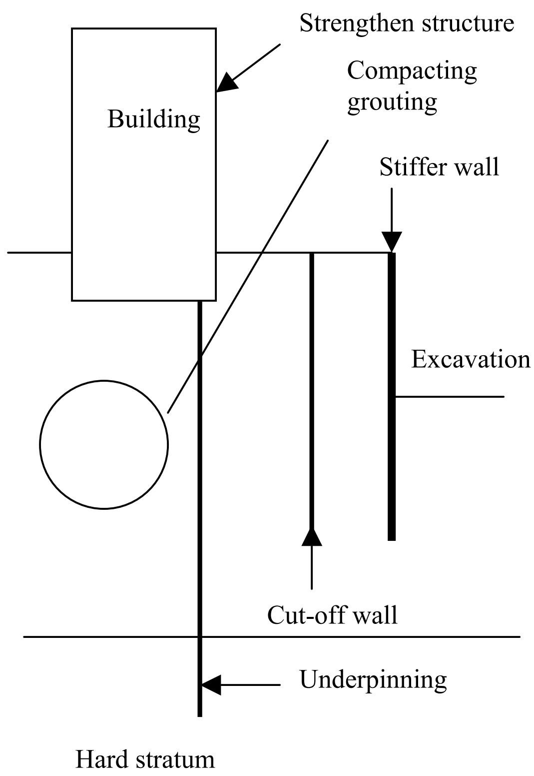

Figure 1. Concept of building protection (Moh and Chin, 1993)

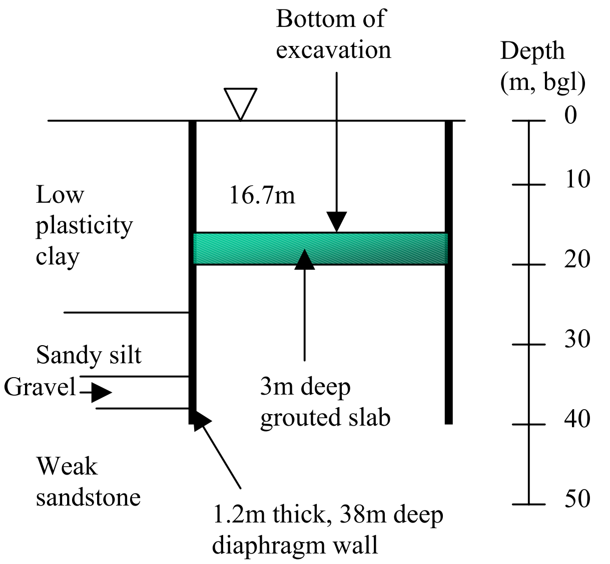

Figure 2. A cross section of the excavation at BL14 station

Figure 4. Underpinning at JDB- Exit A site

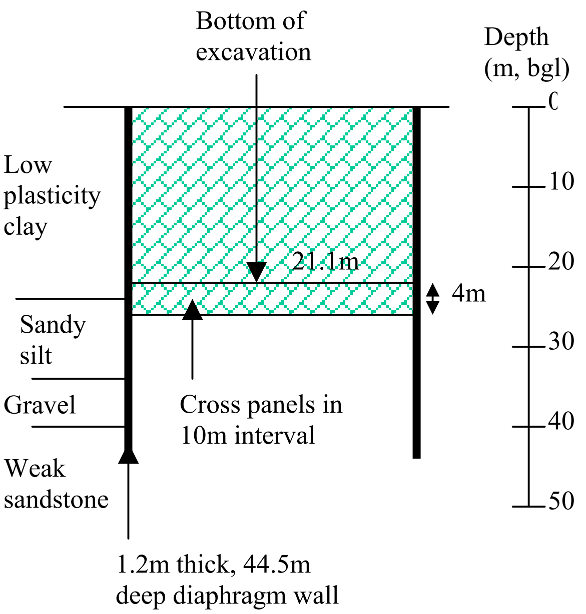

Figure 3. A cross section of the excavation beneath JDB next to BL14 station

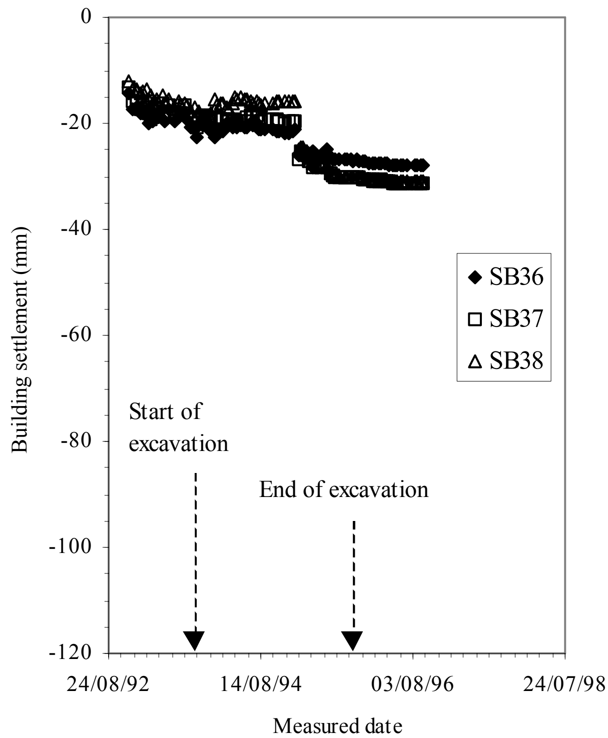

Figure 5. Observed building settlement obtained from station SB36- SB38 at the north end of the BL14 station

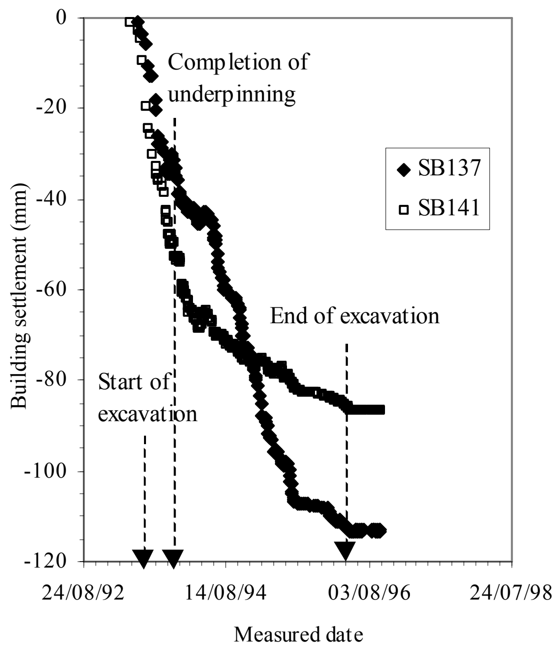

Figure 6. Observed building settlement obtained from station SB137 and SB141 at the south end of the BL14 station

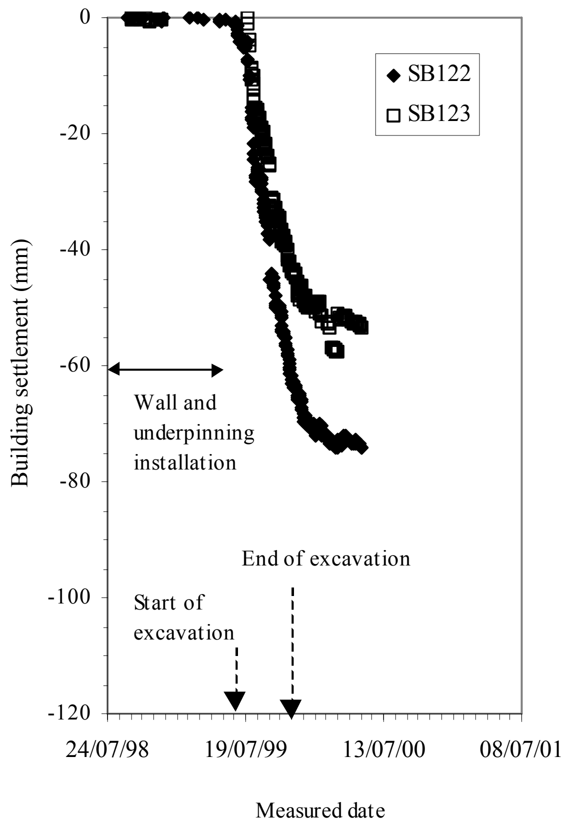

Figure 8. Building settlement of house C1043 induced by the excavation at JDB- Exit A

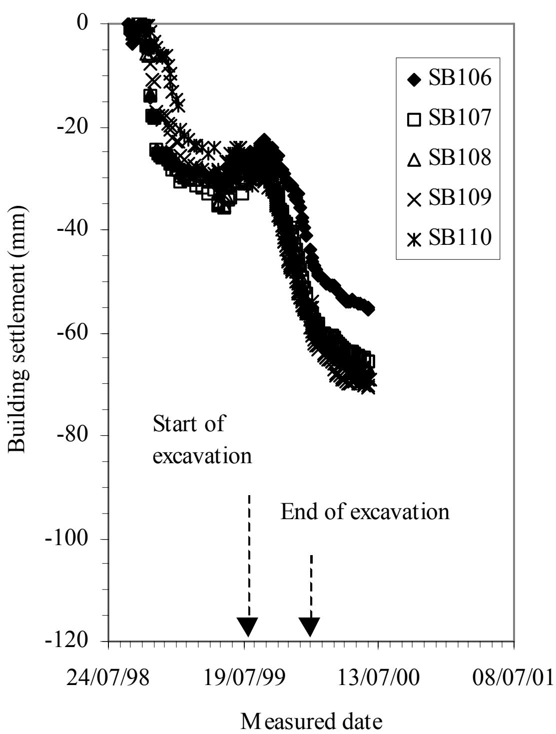

Figure 7. Induced building settlement at JDB- Exit A site

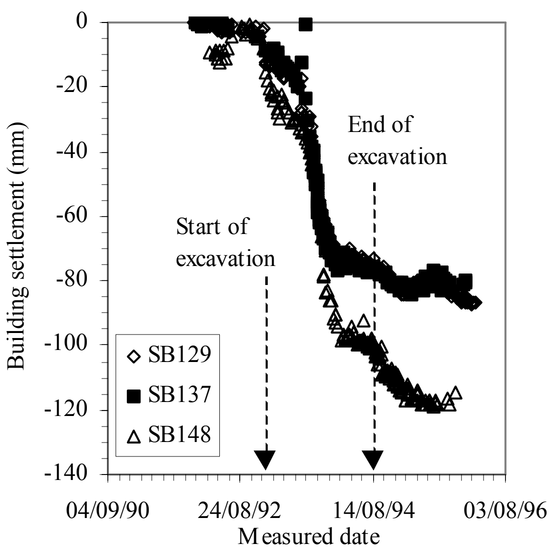

Figure 9. Measured building settlement at BL12 station

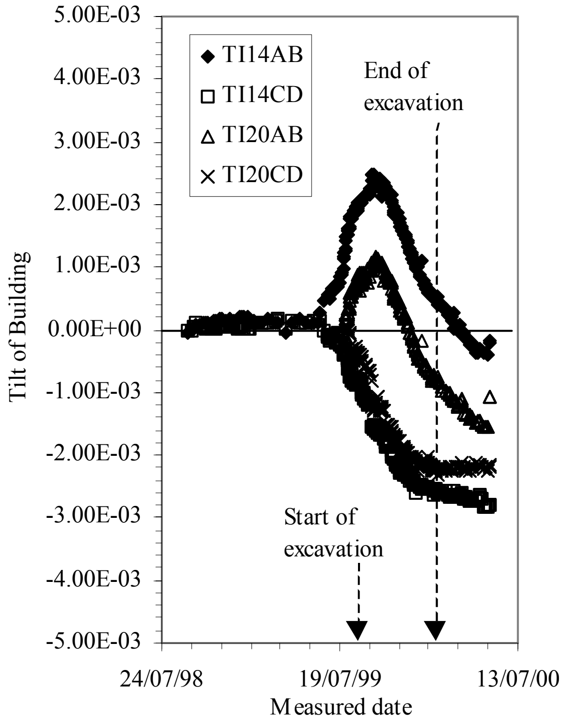

Figure 10. Observed building tilt of house C1043 induced by the excavation at JDB- Exit A

6 CONCLUSION

From field observation at some deep excavations in soft clay ground conditions in Taipei with the protection measures of underpinning and cut-off-piling wall, it may be concluded the underpinning of an adjacent structure is not effectively in reducing the building settlement at these sites. The underpinning would not reduce the building movement if the loads of adjacent buildings were not transferred to the stiffer ground successfully. Also, the tip of contiguous piling walls was not reached the hard soil strata at the sites of JDB-Exit A and Mingshen water tank and it was anticipated to be the reason that the ground movement could not be reduced effectively.

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