Study on the Performance of Foundation Pit Supporting System Considering the Process of Anchor Recycling

ZHENG Quanming¹, LIU Yan²,³, HE Donglin¹ and ZHANG Xiwen²,³*

¹ Shandong Bureau of China Metallurgical Geology Bureau, Jinan, Shandong, 250001, China
² The Engineering Technology Research Center for Urban Underground Engineering Supporting and Risk Monitoring of Shandong Province, Shandong, 250022, China
³ School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, 250022, China
*Corresponding author’s e-mail: cea_zhangxw@ujn.edu.cn

Abstract. The technology of recoverable anchors / cable greatly avoids the disadvantage of traditional anchors / cable, such as non-recyclable, waste of resources and occupy underground space. However, there are many problems existed in the development, design and application processes. Taking a foundation pit project in the city of Jinan as an example, the numerical analysis of the whole construction processes was conducted to study the mechanical behaviour of supporting systems. It is found that the supporting pile has major deformation during the excavation and anchors recycle. For the process of anchor recycle, the bending form of supporting pile transformed from outward to inward. Moreover, the horizontal displacement of pile top increased by 21.4%. The axial force of upper anchor increased during the recycle of lower anchor, for example, the axial force of uppermost anchor increased by 21.3% comparing to the state that no anchor was recycled. Therefore, for the real project of anchor recycling, the internal force redistribution and deformation property of supporting system should be fully considered, to avoid the influence to the surrounding buildings and the foundation pit itself.

1. Introduction

The foundation pit engineering has rapidly expanded in quantity and volume with the development of urban construction and underground space[1], however, in recent years due to land resource constraints and red line problems, using anchors in the supporting system in domestic and foreign projects is limited, as the traditional anchor (cable) is used as a temporary supporting structure. After the main structure is completed, it is no longer functions. It basically remains underground and cannot be taken out, resulting in a large amount of underground garbage. According to statistics, in Guangdong and Beijing alone, thousands of tons of steel strands remain in the ground every year, resulting in a serious waste of materials. In addition, underground anchors (cable) occupy underground space and affect the development and reuse of adjacent blocks. In the current engineering context, recyclable anchor (cable) technology has emerged and is constantly innovating and applying. Recycled steel strands can be reused for resource conservation, efficient use, environmental protection and sustainable development.

Recoverable anchors (cables) can be roughly divided into three types: mechanics recovery, mechanical recovery and chemical recovery[2]. Widely used in the literature and in engineering, there are German DYWIDAG recovery anchors, British SBMA recovery anchors, KTB and IH recovery...
anchor developed by a Japanese company, Yield-Lok anchors developed by JENNMAR of Canada, the step less pressure-regulating anchor cable developed by Beijing Lichuan Foundation Engineering Co. Ltd., the LTRA recyclable anchor developed by Guangzhou Taiji Engineering Co., Ltd., and the fixed-threshold recyclable anchor developed by Wuhan Wujian Machinery Construction Co. Ltd. Many scholars have studied the product development, action mechanism, experimental research, numerical simulation, construction technology, design and engineering application and other aspects of recyclable anchor cable.

There are also many problems in the application of recoverable anchors (cable), such as incomplete recovery of anchor cable and non-recovery of bearing anchor head. Some scholars have conducted a comprehensive analysis on the recovery rate and economic benefits, while the actual project may not only have economic benefits, but must be recycled. In addition, the steel strand of serious damage in the recovery process and the contradiction between the bearing capacity of the recoverable anchor cable and the recovered tension are also difficult problems in the recovery process. Guo Yanming et al. pointed out in the literature that it is also necessary to develop a high recovery rate, high bearing capacity, efficient recovery anchors (cable) and study the construction technology and design calculation method of recoverable anchor cable.

On the basis of literature review, it finds that there are many researches on the recyclable anchors itself, such as the action mechanism, recycling technology and bearing capacity of the recyclable anchors. However, there are few researches on the internal force change and deformation characteristics of the new supporting system in the process of recovering anchor cable. Therefore, based on a foundation pit project in the city of Jinan, considering the process of excavation construction and anchor recovery, the working characteristics of the whole foundation pit anchor supporting system were studied.

2. Project profile and model building

2.1. Project profile

The project is located in a commercial complex foundation pit project in Jinan City. The basement is set as three floors. The excavation depth of the standard section of the foundation pit is 15m. The safety level of the project is level 1 and the important coefficient of the supporting structure is 1.1. The strata revealed in the exploration depth of the site from top to bottom are plain filled soil, silty clay, clay, fully weathered gabbro and strongly weathered gabbro. The physical and mechanical parameters of rock and soil mass are shown in table 1.

| Number | Soil layer            | Unit weight $\gamma$ (KN/m$^3$) | Elastic Modulus $E$ (MPa) | Cohesion $c$ (kPa) | Internal friction angle $\phi$ (°) |
|--------|-----------------------|----------------------------------|--------------------------|-------------------|----------------------------------|
| 1      | plain filled soil     | 18                               | 56.5                     | 10                | 15                               |
| 2      | silty clay            | 18.9                             | 49.35                    | 22.7              | 19.5                             |
| 3      | clay                  | 19.2                             | 66.05                    | 31.2              | 20.6                             |
| 4      | fully weathered gabbro| 17.5                             | 30.75                    | 27.2              | 15.1                             |
| 5      | strongly weathered gabbro | 24                 | 26600                    | 90                | 35                               |

The supporting form of the foundation pit is retaining pile with four recoverable anchors. The retaining pile adopts $\Phi$ 800mm@1500mm bored cast-in-place pile, one pile by one anchor, and the strength grade of crown beam concrete is C30. The anchor design parameters are listed in table 2.
Table 2. Anchors parameters.

| Amounts of anchors | Horizontal spacing (m) | Vertical spacing (m) | Inclination angle (°) | Anchor length (m) | Internal force design (KN) | Prestressed force (KN) |
|--------------------|------------------------|----------------------|----------------------|-------------------|---------------------------|------------------------|
| 1                  | 1.5                    | 3.5                  | 15                   | 27.5              | 479.67                    | 260                    |
| 2                  | 1.5                    | 3                    | 15                   | 21                | 595.16                    | 280                    |
| 3                  | 1.5                    | 3                    | 15                   | 20                | 788.38                    | 240                    |
| 4                  | 1.5                    | 3                    | 15                   | 20.5              | 591.91                    | 260                    |

2.2. FEM Model

Finite element software MIDAS/GTS was used for two-dimensional numerical simulation, and calculation model size was 135m×30m. The boundary conditions are set as follows: the bottom surface is fixed in the x and y directions; The two sides are fixed in the x direction and free in the y direction; The space between the outer wall of the basement and the retaining pile is 1.5m, and backfill is used in the middle. The calculation model is assumed to be a plane strain model, soil and supporting structure are homogeneous medium and isotropic material, soil is assumed to be a Mohr-Coulomb elastoplastic constitutive model, row piles and outer walls of basement are assumed to be beam elements, and prestressed anchor cables adopt embedded truss elements. It is divided into 1148 quadrilateral grid elements, and the calculation model is illustrated in figure 1.

![Figure 1. Computational model diagram.](image)

Before excavating foundation pit, the retaining pile construction and ground stress balance were carried out firstly, and the foundation pit excavation and anchor cable recovery were simulated after displacement clearing. There are 11 construction processes totally, as summarized in table 3.

Table 3. Simulation process.

| Process ID | Construction procedure |
|------------|------------------------|
| Process1   | Excavating the first layer of soil and applying the first anchor. |
| Process2   | Excavating the second layer of soil and applying the second anchor. |
| Process3   | Excavating the third layer of soil and applying the third anchor. |
| Process4   | Excavating the fourth layer of soil and applying the fourth anchor. |
| Process5   | Excavating the fifth layer of soil. |
| Process6   | Building the basement. |
| Process7   | Backfilling the fifth layer of soil and recycling the fourth anchor. |
| Process8   | Backfilling the fourth layer of soil and recycling the third anchor. |
| Process9   | Backfilling the third layer of soil and recycling the second anchor. |
| Process10  | Backfilling the second layer of soil and recycling the first anchor. |
| Process11  | Backfilling the first layer of soil. |

3. Analysis of foundation excavation and recovery process of anchors

3.1. Analysis of lateral deformation of retaining pile

The simulation results of 11 processes were extracted and summarized, and the lateral displacement of the retaining pile was shown in figure 2. It can be seen that during the excavation of the foundation pit, although the retaining pile moves into the pit as a whole, the pile body bends out of the pit because of
the axial tension of the anchor rod, and the displacement of the pile top is the largest. At this time, the outside of the retaining pile is subjected to the greater bending moment tension. For the process of anchor recycle, the bending form of supporting pile transformed from outward to inward, and the overall displacement increases. At this time, the inside of the retaining pile is subjected to a greater bending moment tension. When the last anchor is recovered, the displacement increment is larger than the previous ones.

Figure 2. Horizontal displacement graph of retaining pile for construction process.

Figure 3. Displacement graph of pile top in x direction for construction process.

The displacement of pile top and maximum displacement of pile body is analyzed, as shown in figure 3 above. It can be observed that the displacement of pile top increases greatly in the excavation period and little in the recovery period of anchors. After all the anchors were recovered, compared with that when the bolts were not recovered, the displacement of the pile top increased by 21.4% and the maximum displacement of the pile body increased by 71%.

### 3.2. Axial force analysis of anchor

Figure 4 shows the change of the axial force of the four anchors during the entire excavation of the foundation pit and the recovery of the anchors. Firstly, when the first layer of soil is excavated after applying prestressed force, it will suffer a certain loss. However, with the downward excavation of the foundation pit, the supporting system will be deformed, and the internal force distribution of the supporting structure will also change. The axial force of each bolt will increase in different degrees. When the anchors are recovered, the recovery sequence is from bottom to top. The axial force of upper anchor increased during the recycle of the lower anchor. After the recycle of anchor, the axial force of the first anchor increased most dramatically by 21.3% comparing to the state that no anchor was recycled.
3.3. Analysis of overall deformation of foundation pit

Figure 5 and figure 6 respectively show the horizontal and vertical deformation of the whole foundation pit. It can be seen that the soil layer and the retaining structure above the bottom of the pit will have a large horizontal displacement, while the bottom of the pit will have a large uplift deformation due to unloading.

Figure 5. The displacement contour diagram of the whole foundation pit in x direction after the anchors were recovered.

Figure 6. The displacement contour diagram of the whole foundation pit in y direction after the anchors were recovered.

4. Conclusion

Through the foundation pit excavation of recoverable anchor tensile anchor supporting system and the whole process simulation of 11 process in recycling anchor construction, analysing the deformation and stress characteristics of the supporting system, we can obtain the following conclusions. During
the period of excavation and applying prestressed anchor cable, retaining piles have a deformation into the pit, bending to the outside of the pit. At the phase of anchor recovery, the retaining pile bends and deforms into the pit and the horizontal displacement of the retaining pile top increases. The axial force of upper anchor increased during the recycle of the lower anchor, in which the axial force of the upper anchor increases most dramatically. If the surrounding buildings have strict deformation requirements or the anchor bolt's own bearing capacity is insufficient, recycling anchors will cause a bad impact. Therefore, the deformation and stress characteristics of the supporting system in the process of recycling should be taken into account when designing the supporting system of recoverable anchors.

Funding
This research was funded by the Science and technology research project of Shandong Bureau of China Metallurgical Geology Bureau (2018) and the Key Technology Research and Development Program of Shandong Provincial (grant number 2019GSF111031).

References
[1] GONG xiao-nan, SONG Er-xiang, GUO hong-xian. (2018) Practical projects of foundation pit engineering 7. China building industry press, Beijing.
[2] GUO Yan-peng, LI Shi-min, LI Hong-xin. (2015) Development status and prospect of recoverable anchors. Sichuan Building Science, 41(2): 136-140.
[3] LU Guang-hong, NI Guang-le, MO Hai-hong. (2006) A New Technology of Recoverable Anchors. Geotechnical Engineering World, 9(5): 38-39.
[4] LI Xi-yin. (2008) Application of fixed threshold recoverable anchors in foundation pit supporting. China Water Transport, 8(9): 187-188.
[5] ZHANG Ji-hong . (2012) Recycling excavation support system (RESS) for foundation pits. Chinese Journal of Geotechnical Engineering, 34(S1): 287-291.
[6] WANG Yong-sheng . (2003) Study on mechanic recovering bolt and support mechanism. Coal Science and Technology, 31(12): 48-50.
[7] PANG YOU-shi, LIU Han-long, GONG Yi-jun. (2010) Study of pullout tests of recoverable anchors. Rock and Soil Mechanics, 31(6): 1813-1816+1821.
[8] Yijun Gong. (2007) Study on Pull-out Test and Numerical Simulation of Newly Recoverable Anchor. Hohai University.
[9] SHENG Hong-guang, NIE De-xin, FU Rong-hua. (2003) A Test Study on Removable Anchor. Journal of Geological Hazards and Environment Preservation, 14(4): 68-72.
[10] LI Zhao-ping, HUANG Ming-li, WANG Jian, LI Wentao. (2012) Study on the Recoverable Anchor Cable Supporting Scheme Optimization Design for Metro Foundation pit. Chinese Journal of Underground Space and Engineering, 8(1): 154-160.
[11] PANG You-shi, LIU Han-long, CHEN YU-min. (2009) Numerical simulation of removable anchor pullout test and influence factors. Journal of PLA University of Science and Technology (Natural Science Edition), 10(02): 170-174.
[12] WANG Li-ming, SHI Ming-sheng, XU Lei-yun, WANG Yi-bin, ZHOU Jian-ming. (2010) Retrievable enlarged-end anchor with looped non-sticky steel-string. Chinese Journal of Geotechnical Engineering, 32(S2): 471-474.
[13] QU Yan-bin, GUO Yong-shun. (2008) Study on Construction Technology for Recyclable Prestressed Anchor Cable. Guangdong Architecture Civil Engineering, 5: 27-29.
[14] WANG Wei-dong, WENG Qi-ping, WU Jiang-bin. (2012) Design and application of large-diameter retrievable anchor cable in soft soil area. Building Structure, 42(5): 177-180.
[15] ZHAO Qi-jia, LIU Zheng-gen. (2012) Application of recycling anchor cables in support of excavations. Chinese Journal of Geotechnical Engineering, 34(S1): 480-483.
[16] YI Mao-sen, XIE Wei. (2002) Comprehensive analysis on recovery rate of recoverable bolt. Coal Science and Technology, 30(S1): 52-54.