Effect of Foundation Pit Protective Facing Thickness on the Construction Stability of Open-Cut Underpass

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Abstract. To ensure the safety and stability during the construction process of open-cut underpass, this paper takes the Xinchun Road underpass project in Chongqing as the research background, adopts numerical calculation method to establish the "excavation of foundation pit-slope protection-structural construction-back filling" simulation model for the whole construction process. The deformation and force characteristics of different construction stages of soil and support system are analysed, to summarize and optimize the safety measures of the construction process of open-cut underpass. The research results show that: reasonable control of the slope rate can effectively control the plastic deformation of the surrounding rock in the stage of pit excavation. The thickness of foundation pit protective facing for the impact of the project is mainly embodied in the back filling stage. With the increase in the thickness of protective facing, the maximum deformation of the rock-soil mass in each direction has increased. The foundation pit protective facing for the safety and stability of the whole process of the construction of open-cut underpass is very limited. The design and construction should be strengthened to protect the key protection areas ensure the safety and stability of the whole process of the open-cut underpass. The results can provide optimisation ideas and design references for the protection of open-cut underground structures.

Keywords: open-cut underpass; foundation pit support; numerical simulation; ground settlement

1 Introduction

Underpass has assumed an increasingly important role in urban livelihood, traffic, municipal and human defence. However, as the development of urban underground space continues to complicate the process, bringing challenges to the safety and stability control of underpass construction.

Many scholars have carried out a series of studies on the construction stability of open-cut underpass (or tunnels). Fu et al[1-2] established a risk evaluation system to

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analyse the construction risk and control decision-making of cut-and-cover tunnels in response to the problem that there are many potential risk factors that are difficult to identify in the process of open-cut tunnel. Kim et al[3] used numerical simulation to optimise the relevant design parameters in the process of open-cut tunnel construction. Son et al[4] used theoretical analysis and numerical calculation methods to analyse the impact of open-cut tunnel excavation on existing buildings. In addition, some scholars have also carried out research on the environmental impact of open-cut tunnels[5], cost control[6] and other aspects.

The current design theory of pit support measures is not mature enough, which brings challenges to the reasonable arrangement of pit support measures. Therefore, this paper takes the Xinchun Road underpass project in Chongqing as the research background, and adopts the numerical simulation software ABAQUS to analyse the stability of the construction of the open-cut underpass under the condition of different thickness of foundation pit protective facing, to provide a design reference for the optimization of the foundation pit support measures in open-cut tunnels.

2 Engineering Background

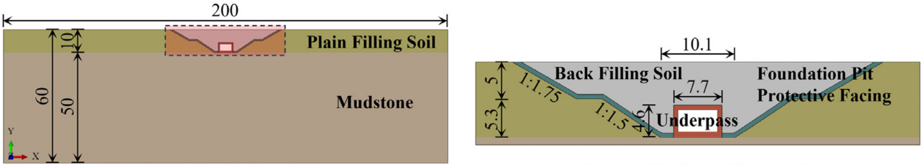
The proposed site consists of plain fill and mudstone, which is generally stable and suitable for engineering works. The structure type is single-hole underpass culvert. The calculated height is 3.825 m and the calculated span is 7.1 m. The thickness of the top plate, bottom plate and side walls are 650 mm, 800 mm and 600 mm respectively, and the total length is 122.25 m.

The construction process is as follows: measurement and sampling→ foundation pit excavation→ foundation bearing capacity testing→ bedding→ steel processing tying→ underpass floor construction→ underpass wall and roof construction→ deformation joints and cave waterproofing layer construction→ back filling→ inspection and acceptance. The excavation of the foundation pit of the underpass adopts open-cut secondary sloping, and the slope rate of sloping is 1:1.75 and 1:1.5 from top to bottom. The foundation pit protective facing is supported by shotcrete.

3 Model Building and Working Condition Arrangement

3.1 Numerical Modelling

Combined with the site exploration data and engineering design parameters, the numerical simulation software ABAQUS is used to simulate the whole construction process of the project. The size of the model is 200 m (X direction) × 60 m (Y direction) × 20 m (Z direction), as shown in Fig.1. The calculation process of the model is reasonably simplified. Combined with the force characteristics of the material, the rock-soil mass adopts the Moore-Coulomb constitutive, and the concrete material adopts the linear elasticity constitutive. The calculation process uses 5 calculation and analysis steps, and its specific implementation process is shown in Fig.1(c).



(a) Whole of the model (b) Localisation of the model

(c) Calculation and analysis steps

Fig. 1. Numerical model

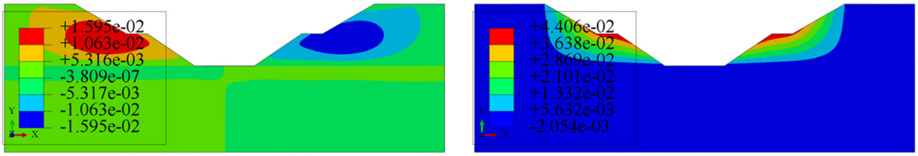
3.2 Working Condition Arrangement

Selects 4 cm, 6 cm, 8 cm 3 different thicknesses of shotcrete to support the foundation pit, respectively, for the working conditions 1, 2 and 3, to analyse the whole process of underpass construction within the calculation area of the deformation field, the change rule of the stress field, and then provide theoretical support for the design of the foundation pit support of open-cut underpass.

4 Numerical Results

4.1 Deformation Analysis

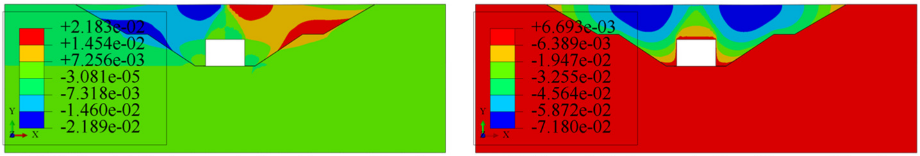
The deformation cloud diagrams of the calculated area for each working condition after pit excavation and back filling were extracted as shown in Fig.2 to Fig.3.



(a) Horizontal displacement (b) Vertical displacement

Fig. 2. Displacement cloud diagrams of foundation pit excavation (unit: m)

From Fig.2, after excavation of the pit, the rock-soil mass at the original pit location unloads pressure, the deformation at the location of the second slope transition platform is the largest, and the displacement in the vertical direction is dominant. After back filling, the deformation in the vertical direction of the surrounding rock is dominant, and under the influence of the self-gravitational impact, the backfilled soil body produces downward deformation, but by the supporting effect of the underpass support structure, the maximum settlement deformation occurs on the two sides of the central axis.



(a) Horizontal displacement of working condition 1 (b) Vertical displacement of working condition 1

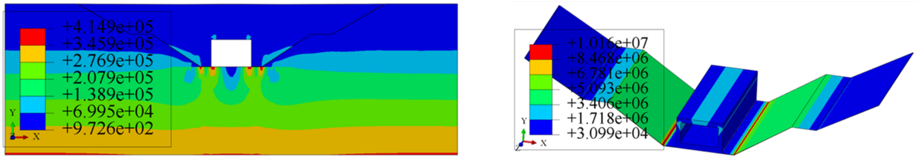
Fig. 3. Vertical displacement cloud diagrams of working condition 1 after backfilling (unit: m)

With the increase of the thickness of the foundation pit protective facing, the deformation in all directions increased. Evidently, the deformation increased within 2.01% for working condition 2 and within 3.29% for working condition 3.

4.2 Stress Analysis

The stress cloud diagrams of rock-soil mass and support structure for working condition 1 are shown in Fig.4(a) and Fig.4(b).

As shown in Fig.4, after pit backfilling, stress concentration occurs in the contact area between pit protective facing and underpass support structure and surrounding rock, and the stress is within 0.46 MPa. In the actual project, brick-built drain was installed in this area, and the quality of backfill of the brick-built drain and the support measures in this area should be strengthened during the construction process to avoid local damage. The maximum stress of the pit protective facing structure occurs in the base part, and the maximum stress reaches more than 10.16 MPa, which should be strengthened in the construction process. With the increase of the thickness of the pit protective facing, the supporting role of the pit protective facing is more obvious, and the maximum value of the stress of the surrounding rock and support structure have increased.



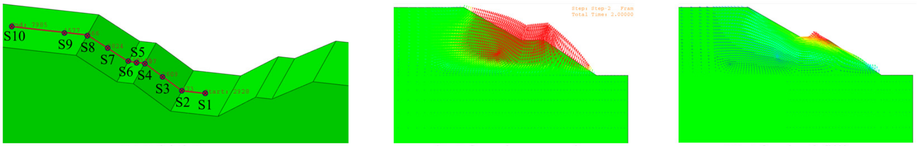
(a) Rock-soil mass of working condition 1 (d) Support structure of working condition 1

Fig. 4. Stress cloud diagrams of working condition 1 after backfilling (unit: Pa)

5 Construction Stability Analysis

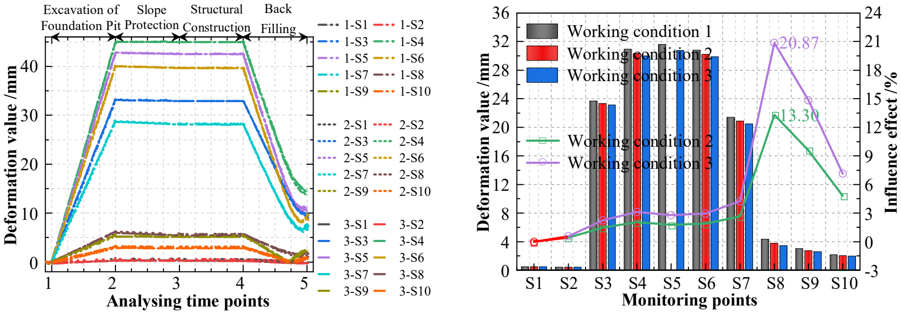
5.1 Slope Stability Analysis

To further analyse the slope stability during the construction process, 10 monitoring points were arranged in the middle of the model, as shown in Fig.5(a), and the deformation results at the corresponding locations were extracted as shown in Fig.6.



(a) Initial State (b) After pit excavation (c) After backfilling

Fig. 5. Slope condition at different stages



(a) Displacement at each monitoring point (b) Deformation and influence effect in backfilling process

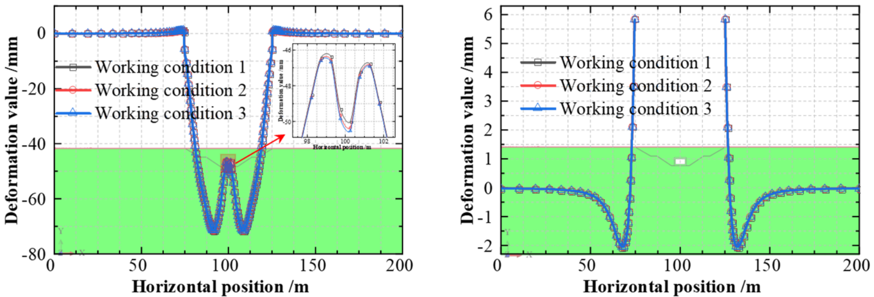
Fig. 6. Displacement analysis at each monitoring point

From Fig.6(a), the deformation of rock and soil is larger in the process of excavation and backfilling of the foundation pit. Combined with Fig.5(b)~ Fig.5(c), the excavation process caused the slope to bulge and converge to the inside of the pit due to the release of soil pressure in the excavation part, and the backfilling process caused the deformation to be reduced due to the extrusion effect of the backfilled rock-soil mass on the slope. The difference in the thickness of the pit protective facing is mainly reflected in the backfilling stage. And with the increase of the pit protection facing, the deformation of the slope in the backfilling process is reduced.

As shown in Fig.6(b) for each condition backfilling process deformation and the effect of the thickness of the pit protection facing. The deformation at each monitoring point during backfilling is reduced after the thickness of pit protection facing is increased, of which the effect is not significant at the position of S1, and the effect of working condition 2 and working condition 3 is the most obvious at the position of S8, which reaches 13.30% and 20.87% respectively.

5.2 Analysis Of Ground Settlement

From 4.1, the whole construction process of pit excavation and backfilling process has a greater impact on the deformation around the pit. Therefore, the vertical displacement at the location of the ground surface centre line at these two moments is extracted to characterise the ground settlement, and the results are shown in Fig.7.



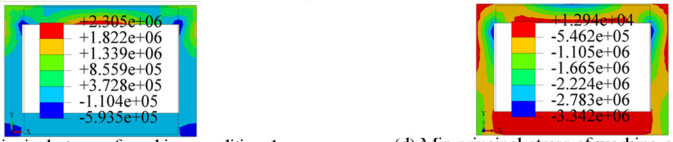
(a) After pit excavation (b) After backfilling

Fig. 7. Distribution of ground settlement

From Fig.7, after excavation pit, there is a heave in the range of 3 m near the pit, and the amount of heave is within 6 mm. Ground settlement occurred from 3 m to 25 m from the pit, with a maximum value of 2.05 mm at 8 m from the pit. After backfilling, it can be seen from Fig.7(b) that the change of the pit protective facing thickness has extremely weak influence on the ground settlement around the pit, and it has certain influence on the ground settlement right above the underpass support structure: with the increase of pit protective facing thickness the ground settlement right above the underpass support structure becomes larger, but the influence effect is only within 1.06%.

5.3 Structural Stability Analysis of Underpass Support Structure

The stress characteristics of underpass support structure are directly related to the safety and stability of the underpass construction and later operation. The maximum and minimum principal stress distribution of the cross-section of the underpass support structure after pit backfilling are shown in Fig.8.



(a) Max principal stress of working condition 1 (d) Min principal stress of working condition 1

Fig. 8. Stress distribution of underpass support structure (unit: Pa)

The stress distribution trend of the 3 conditions is consistent, the maximum value of compressive stress is distributed in the top of the side wall, and none of them is greater than 3.35 MPa; the maximum value of tensile stress is distributed in the middle of the roof plate, and the maximum value is not greater than 2.305 MPa; the maximum value of visible stress is not greater than the permissible stress of concrete (permissible compressive stress 2.43 MPa), and it can be assumed that the stability of the underpass support structure is good in the process of construction. With the increase of pit protective facing thickness, the stress value of the underpass support structure is reduced, and the effect is within 0.17%.

6 Conclusions

(1) After pit excavation, the deformation at the position of the transition platform of the secondary slope release is the largest, and the largest settlement deformation after backfilling of the foundation pit occurs at the two sides of the central axis; with the increase of the pit protective facing thickness, the largest deformation in each direction increases, and the increase is within 3.29%.

(2) Stress concentration occurs at the location of brick-built drain after backfilling, the quality of backfilling should be ensured and the support measures should be strengthened in the construction process; with the increase of pit protective facing thickness, the maximum value of the stress in the surrounding rock and pit protective facing structure are increased.

(3) With the increase of pit protective facing thickness, the ground settlement becomes larger, the underpass support structure stress value is reduced, the effect is within 1.06%.

For this paper relies on the project, in the adoption of reasonable control of the slope rate based on the pit protective facing for the process of open-cut underpass construction protection is very limited. For similar projects, the protection of key protective parts should be strengthened in the process of design and construction to ensure the safety and stability of open-cut underpass construction.

References

1. Fu J., Xu X., Chen B., et. al. (2022) Comprehensive evaluation of risk coupling of collaborative construction of open excavation highway tunnel and adjacent subway. Journal of Highway and Transportation Research and Development, 39(08):159-165. https://doi.org/10.3969/j.issn.1002-0268.2022.08.021
2. Yang Y., Wang C., Zhu G. et. al. (2024) Safety evaluation of structures and utilities within right-of-way of highways of open-cut tunnel under-crossing the pbridges based on combined weighted-set-pair analysis. Highway, 2024(04):200-207. https://doi.org/0451-0712(2024)04-0200-08
3. Kim J., Kim J., Rehman H., et. al. (2020) Ground stability analysis in non-open-cut tunneling method using small-diameter steel pipe piles. Applied Sciences-Basel, 10(19): 6906. https://doi.org/10.3390/app10196906
4. Son M., Cording, Edward J. (2020) Estimation of building damage in a 3D distorting structure to tunnel and underground excavation-induced ground movements. Tunnelling and Underground Space Technology, 97:103222. https://doi.org/10.1016/j.tust.2019.103222
5. Richardson C., Rutherford S., Agranovski I. (2019) Particulate emission rates for open surfaces in Australian open cut black coal mines. Journal of Environmental Management, 232(15): 537-544. https://doi.org/10.1016/j.jenvman.2018.11.020
6. Lu L., Yue R., Huang C., et. al. (2023) Carbon-reduce calculation and scheme selection study of foundation pit supporting in open-cut tunnel. Chinese Journal of Underground Space and Engineering, 2023, 19(S2):785-793. https://doi.org/1673-0836(2023)S2-0785-09.