Influence of burial depth on Soil Arch in Utility Tunnel

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Abstract. In mollisol subsurface excavation, the selection of the vertical load of utility tunnel will directly affect the economy and safety of the project. It is necessary to consider the effect of soil arch on the design of the integrated excavated tunnel in the mollisol stratum, which is related to the value of vertical load. From the aspects of stress field variation and inhomogeneous deformation, to obtain the results of the influencing factor, buried depth, we analyzed the action mechanism of soil arch pressure. In mollisol subsurface excavation of utility tunnel, the deeper buried depth, the more obvious the arch effect is. The influence of buried depth on the arch effect in mollisol has certain guiding significance for the value of vertical load of mollisol tunnel, which can provide the basis for the design of integrated utility tunnel.

1. Introduction
For mollisol underground engineering, the selection of vertical load is directly related to the economy and safety of the project. From the aspects of stress field variation and inhomogeneous deformation, to obtain the results of the influencing factor, buried depth, to guide vertical load design in mollisol subsurface excavation of utility tunnel, we analyzed the action mechanism of soil arch pressure. Some scholars obtained the relationship between soil arch effect and depth of embedment [1]. Some learners defined the soil arch pressure, through the stress analysis [2]. Academician discussed the existing form of arch springing [3]. Many domestic scholars discussed the vertical load calculation method for shield tunnel structure design in mollisol stratum, and proposed some practical calculation method for vertical load [4-9]. All above are the analysis of the arch effect on the circular section structure. It is not common for the study of the soil arch effect of rectangular section structures such as utility tunnel. In this paper, the finite element software, ANSYS, is used to establish the three-dimensional model of utility tunnel for the analysis about influence factors of the soil arch effect of the rectangular utility tunnel. This article will be simulated from the following aspect: Different burial depth: Utility tunnel simulation under different buried depth is carried out to analyze the change regulation of arch effect, and with the changing law of the buried depth, provided a better buried depth for utility tunnel.

2. Methods
The calculation method for exertion of soil arch effect \( K_M \)

In most cases, the soil arch effect for utility tunnel structure can’t be described simply as before. In order to reflect the influence of redistribution of overburden pressure for the whole structure, the soil arch effect is described by the method of replacing the single point load with the mid span bending moment values of roof, by \( K_M \).
\[ K_M = \frac{M_j - M_g}{M_j} \times 100\% \]  

\( K_M \) — degree coefficient of soil arch effect in utility tunnel
\( M_j \) — mid span bending moment of roof without the soil arch effect
\( M_g \) — mid span bending moment of roof with the soil arch effect

In this text, choosing entity unit as ANSYS model, and outputting numerical deformation of the model.

Calculation method without the soil arch effect: let upper roof load equivalent to uniform load, the value of mid span bending moment without soil arching \( M_j \) effect is simplified by the following simplified diagram.

Figure 1. Simplified diagram 1.

Calculation method with the soil arch effect, the simplified calculation diagram is as follows:

Figure 2. Simplified diagram 2.

3. Depth factor

3.1 Geometric parameter

Under the conditions of the buried depth of 4m, 8m, 12m and 16m, comparing the KM of the 28m wide model and the 32m (7 times width of structure) width model by the simulation calculation. It turned out that it has little effect on soil arch effect in utility tunnel. So in order to reduce the amount of calculation, the 28m width model is taken in this paper.

Figure 3. \( K_{Mj} \) changes of different depth.

The geometric parameters of utility tunnel structure model take width 8m, height 4m. The total model width of 28m, the total height of 32m, as follows:
3.2 Materials
Adopting the Drucker-Prager yield criterion of ANSYS, or D-P yield criterion for short.

Table 1. Parameters of D-P constitutive model.

| Soil Layer    | Depth (m)  | Density (kg·m⁻³) | Elastic Modulus (Mpa) | Poisson Ratio | Internal Friction Angle (°) | Cohesion (kPa) |
|---------------|------------|-------------------|-----------------------|---------------|-----------------------------|----------------|
| Miscellaneous | 0.4-1.19   | 1930              | 4.37                  | 0.2           | 14                          | 24             |
| Clayey Silts  | 1.19-9.20  | 1740              | 2.49                  | 0.4           | 12                          | 11.7           |
| Mollisol      | 6.99-10.19 | 1940              | 8.8                   | 0.4           | 13                          | 15             |

Table 2. Parameters of concrete.

| Density (kg·m⁻³) | Elastic modulus (Mpa) | Poisson ratio |
|-------------------|-----------------------|---------------|
| 2.8×10³           | 5×10³                 | 0.2           |

In order to obtain the vertical load with soil arch effect, under the conditions of different buried depth in the soft, consider the shield working conditions when the buried depth is 1H, 2H, 3H, and 4H respectively.

3.3 Soil arching caused by different depth shields
The numerical analysis method is used to establish the calculation model, to obtain the effect of excavation to soil arching effect under different conditions, such as data analysis results of soil deformation, soil pressure and structural stress.

Firstly calculate the ground stress field. Secondly loading the calculated stress field on the unexcavated soil. Then simulating soil excavation and placement by using life and death units. The simulation results are shown as follows:

(a) Deformable graph (5 times magnification); (b), (c), (d) nephogram

Figure 5: Graph of 1H.
2H stress: (a) Deformable graph (5 times magnification); (b), (c), (d) nephogram
Figure. 6 Graph of 2H.

3H stress: (a) Deformable graph (5 times magnification); (b), (c), (d) nephogram
Figure. 7 Graph of 3H.

4H stress: (a) Deformable graph (5 times magnification); (b), (c), (d) nephogram
Figure. 8. Graph of 4H.

3.4 Analysis

Table 3. Buried depth and soil arch effect.

| Depth | Buried Depth (m) | Overlying Soil Stress (kPa) | Without Soil Arch Effect | With Soil Arch Effect |
|-------|------------------|-----------------------------|--------------------------|-----------------------|
|       |                  |                             | Mid-span Deflection (mm) | Mid-span Moment (kN·m) | K_M     |
| 1H    | 4                | 70.07                       | 12.71                    | 35.74                 | 13.34   | 33.32   | 6.8%    |
| 2H    | 8                | 138.28                      | 24.22                    | 68.12                 | 24.77   | 61.87   | 9.2%    |
| 3H    | 12               | 210.41                      | 35.04                    | 98.54                 | 33.43   | 83.50   | 15.3%   |
| 4H    | 16               | 286.45                      | 48.32                    | 135.91                | 43.50   | 108.65  | 20.1%   |
According to the analysis, it is found that, due to the constraint of the side plate to the roof, stiffness of the end of the roof is larger than that of middle comparatively. Therefore the stress concentration is produced at the end of the top plate, forming obvious arch foot at the same time; the unloading phenomenon of vault is not obvious in a certain depth range, which is related to the width of the structure section and the setting of the soil parameters. When the buried depth is less than 3H, the unloading effect is not significant, so for safety, equivalent uniform load of overlying soil can be used as the design load. In other words the unloading effect, which is caused by the redistribution of the internal force of the soil, can be ignored during the calculation of shield utility tunnel model, whose buried depth is less than 3H. In mollisol, with the increase of buried depth, the proportion of KM increases and the arch effect of soil is more obvious. Excavation of shield method causing the active deformation of the surrounding soil, which causes soil pressure in the excavated area sharply reduced. Disturbance area of soil arch is formed above the structure because of characteristics of soft soil and effect of disturbed geostress. Exertion of shear strength of the soft soil makes the soil deformation, the internal force of the soil is redistributed, and the part reaches the limit equilibrium state. In stratum where the buried depth is more than 3H, the unloading capacity of soil can reach more than 15%. Therefore, the design of vertical load in deep mollisol stratum, the unloading effect of soil can be fully considered, which makes the design more economical and reasonable.

4. Conclusions
(1) In the deep mollisol stratum, due to the exertion of the shear strength of soil, the relationship is nonlinear increase between soil pressure of utility tunnel structure and shield buried depth.
(2) The greater the buried depth of the tunnel in mollisol, the greater the arch effect is. When the buried depth is up to 4H, the arch effect is 16.29%. At this time, it is more economical to consider the redistribution of internal force, when choosing the value of vertical load and computing model.
(3) Due to different soil properties and cohesion of different soil will lead to soil arching effect play a great difference, specific conditions should also be specific analysis. The situation described in this paper provides an optimal design for utility tunnel. It has certain guiding significance for the vertical load of mollisol utility tunnel, which can provide the basis for the design of utility tunnel of different buried depth of mollisol in the later period.

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