The Effect of Section Width on Soil Arch in Utility Tunnel

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Abstract. The design of the section width of utility tunnel will directly affect the distribution of the internal forces of the structure, it will directly affect the economy and safety of the project. From the aspect of stress field variation, inhomogeneous deformation and the changes of structural stiffness, to obtain the results of the influencing factor (width of the cross-section), we analysed the action mechanism of soil arching pressure. Within a certain range, the narrower the width is, the more obvious the effect is. The changes of the section width results in the changes of the structural stiffness, which is one of the influencing factors of soil arch in utility tunnel. The influence of cross-section width 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
During the excavation process of utility tunnel, due to the self-bearing force of the soil, the shear strength of the soil is gradually exerting, which leads to the deviation of the force transfer to resist deformation, thus producing the soil arching effect. Under loading effect, soil spontaneously regulate the path of stress transfer, and realize the stress redistribution, so as to achieve homeostasis. The soil arching effect has been approved in early 1936 by Terzaghi through door test, and described the stress distribution of soil arches, proposed the existence conditions of soil arching effect by the same time. Under different shield tail gap, burying depth, diameter and different surrounding rock conditions, the variation of soil pressure, soil displacement and soil particle contact force has been concerned [1]. Through 3D numerical analysis of the arching effect, the process and mechanism of stress arching effect in soil were studied [2]. Enlarging the particle diameter and frictional coefficient, decreasing porosity and trapdoor width will not only enhance the effect of soil arching but also narrow the influence range of soil arching [3]. One physical model test by scholar and the data from the literature were used in this study to investigate the progressive development of two-dimensional soil arch with relative movement for different geotechnical applications [4]. The influence of the internal friction angle and the dilation angle as well as the influence of the thickness of the backfill on the size of arching and the redistribution of pressures from the soil onto the structure was extensively discussed [5]. A series of 2D model tests have been undertaken to investigate soil arch in piled embankments with or without geosynthetic reinforcements [6]. The data obtained both from the experimental tests and the numerical modelling in the literature demonstrates the importance of understanding and considering the partially-mobilized soil arch under certain conditions [7]. Previous studies have shown that it is necessary to consider the effect of soil arch when designing underground engineering, especially for mollisol underground works. Besides, as a new trend of underground infrastructure construction, utility tunnel needs more theoretical support. This article will be simulated from the following aspect: different structure width: Without changing the stiffness
condition, compared with arch effect of the comprehensive corridor under the different section width, provided a better section width for utility tunnel.

2. Methods

The calculation method for exertion of soil arching effect $K_M$. Description method about soil arching effect in underground engineering, the common form of tunnel section is circular cross-section and horseshoe cross-section, due to the shape characteristics, the description of the soil arching effect can be obtained directly by comparing the ratio of the overlying soil load ($\gamma h$) to the value of the vertex load of the simulated results. In most cases, the cross-section of utility tunnel is rectangular, and load distribution has an impact on the entire roof of structure, so, the soil arching 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, we defined a parameter $K_M$ to describe the effect. Parameter is expressed as follows:

$$K_M = \frac{M_j - M_g}{M_j} \times 100\%$$  \hspace{1cm} (1)

$K_M$ —— degree coefficient of soil arching effect in utility tunnel
$M_j$ —— mid span bending moment of roof without the soil arching effect
$M_g$ —— mid span bending moment of roof with the soil arching effect

Calculation method without the soil arching effect: the effect is simplified by the following simplified diagram.

$$\begin{cases} M_j = \frac{q l^2}{24} \\ f = \frac{q l^4}{384 E I} \Rightarrow M_j = \frac{384 f \times E I}{24 l^2} \end{cases}$$  \hspace{1cm} (2)

Calculation method with the soil arching effect, the simplified calculation diagram is as follows:
Indirectly solving the mid span bending moment value of structural roof, In this way, the overall deformation of the structural roof can reflect the redistribution of the internal force of the soil, not only a numerical problem of a certain point.

3. **Width factor**

3.1. **Geometric parameter**

The geometric parameters of utility tunnel structure model take width 8m, height 4m. The total model width of 28m, the total height of 20m, was showed as follows:

3.2. **Materials**

Adopting the Drucker-Prager yield criterion of ANSYS, or D-P yield criterion for short, which is the approximation of Mohr-Coulomb criterion. This criterion takes into account the volume expansion caused by the yield criterion, and is suitable for granular materials such as soil and rock mass.

| Soil Layer | Depth (m) | Density (kg·m⁻³) | Elastic Modulus (Mpa) | Poisson Ratio | Internal Friction Angle (°) | Cohesion (kPa) |
|------------|-----------|-------------------|-----------------------|---------------|-----------------------------|----------------|
|            |           |                   |                       |               |                             |                |

Figure 1. Calculation model.
### Table 2. Parameters of concrete.

|                | Density \((\text{kg}\cdot\text{m}^{-3})\) | Elastic modulus \((\text{Mpa})\) | Poisson ratio |
|----------------|------------------------------------------|----------------------------------|---------------|
|                | 2.8×10³                                | 5×10³                            | 0.2           |

3.3. Soil arch caused by different width

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. In this paper, soil arching effect is reflected by the value of Km. While considering the factor of cross section width, it is noted that the width of the section has a great influence on stiffness of the structure. Stiffness of side plate will be revised while the width of the cross section is changed, so as to ensure that the width of the section is the only variable. Linear stiffness: \(k = \frac{E}{t}\). It can be seen from the formula that the stiffness of the roof will be increased by reducing the span. In this paper, stiffness of the side plate is revised by increasing the cross section height of the side plate, to ensure the relative stiffness is constant.

### Table 3. Stiffness magnification.

| Span (m) | 8   | 7 | 6 | 5 | 4 |
|----------|-----|---|---|---|---|
| Stiffness Magnification | 1   | 1.14 | 1.33 | 1.60 | 2.00 |

![Figure 2. Stress nephogram of structure section width changing.](image)

From above diagrams, it can be found that, within the section width of the 8m-4m, and with decrease of the width of the section, internal force distribution of soil gradually forms the arch foot from the end.
of the roof and expands to form the complete arch above the top of the roof, soil arching effect is more and more obvious.

Table 4. Cross section width and arch effect.

| Cross section width (m) | Without Soil arching effect | With Soil arching effect |
|-------------------------|-----------------------------|-------------------------|
|                         | Deformation (mm) | Mid span bending moment (kN·m) | Deformation (mm) | Mid span bending moment (kN·m) | KM |
| 8                       | 35.04          | 98.54                     | 33.43          | 83.50                     | 15.3% |
| 7                       | 20.70          | 103.52                    | 193.62         | 85.97                     | 17.0% |
| 6                       | 11.20          | 55.99                     | 9.98           | 44.33                     | 20.8% |
| 5                       | 4.83           | 24.17                     | 4.27           | 18.94                     | 21.7% |
| 4                       | 1.43           | 7.16                      | 1.23           | 5.45                      | 23.8% |

It can be proved by the above table, within the section width of the 8m-4m, and with decrease of the width of the section, soil arching effect is becoming more and more obvious. With reduction of 2m, its soil arching effect increased by about 4% averagely. Therefore, when designing the section of soft soil utility tunnel, we should pay attention to the design factors of section width, so that we can cost saving better under the condition of ensuring the safety of the structure.

4. Conclusion
Soil arch is a common phenomenon in geotechnical applications, and it affects distributed loads on structures. Through this numerical simulation with different burial depth and different section width, the following conclusions can be made:

1) By comparing and analysing the soil arching effect within different buried depth, 8m, 7m, 6m, 5m and 4m, it’s obvious that, in a certain width range, the effect of soil arch increases with the decrease of the width.

2) The exertion of the soil arching effect is a multi-factor nonlinear problem. It is not only related to the depth of the burial and the width of the section, but also on material parameters of soil (such as cohesion, angle of internal friction, moisture content, etc.) and stiffness of structural and other factors. The situation described in this paper provides an optimal design for utility tunnel, but the specific situation should be analysed specifically.

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