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# The Analysis of the Insufficient Lining Thickness and Cavity on Tunnel Deformation

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**Abstract:** With the expansion of the construction of highway, insufficient lining thickness and cavity defect become commonplace in the tunnel operation. Based on the "formation - Structure" method for simulation for different parts and different defect degrees of the tunnel, this article analyze the model of insufficient lining thickness combine with cavity and the single model of the insufficient lining thickness on the level of convergence and vault settlement by the finite element analysis software MIDAS / GTS.

**Keywords:** Tunnel lining; Insufficient lining thickness; Deformation; Numerical analysis

## 1. Introduction

Nowadays, with our transportation infrastructure construction scale expanding, the highway and railway construction rapidly developing, in order to improve the linear of western mountain areas, and lower longitudinal, which is to ensure road safety, comfort and quickness, the number of road tunnels and the proportion of the total route mileage is increasing. According to investigate, the tunnels that has been built have many different degree detects, such as insufficient lining thickness, cracks, deformation and water leakage and others.

When the tunnel lining thickness is insufficient, the tunnel will have a greater deformation, which will impact on the construction clearance and traffic clearance; at the same time, when a serious shortage of thickness occurs, the tunnel lining will even break, collapse and cause other catastrophic consequences. When cavities exist in the tunnel lining, it will cause the tunnel biasing, lowering down, loosely pressure and inadequate bearing capacity. Therefore, the analysis of the insufficient lining thickness on tunnel deformation is significant.

Currently, there are many researches concerning the insufficient lining thickness and cavity on the stability of the structure, such as: Liu Yingcai[1]check the position and size of the insufficient lining thickness by ground penetrating radar, use the stratigraphic structure method and load structure method check the structural safety of the section of the second lining defect, analyze that constructional deficiency is harmful for the highway by the results of the checking and conclusion, and put up the corresponding preventive measures and treatment methods.

Zhou Qiang[2] uses the semicircular to simulate the cavity, under the situation of a fixed depth, he analyzes the cavity on safety oft as the surrounding rock and lining by combining the size and position of the cavity. Wang Hualao [3] establish the calculation model of the insufficient lining thickness for the different forms of support of the Ⅲ and Ⅳ surrounding rock. Under the condition of no detects, he compare the internal force and safety factor for the each position of the tunnel lining, and analyzes the insufficient lining thickness on lining safety by numerical calculation, which depends on the different degree and width of the insufficient lining thickness.

Zhou Feng and Liang Tailue [4] study the insufficient second lining thickness on tunnel structure by three-dimensional numerical simulation depending on the design specifications. Shen linjie [5] analyzes the discrepancy between the designed secondary lining thickness and actual construction under the specific tunnel engineering background, he chooses the typical lining section, uses the FEM, build the numerical model, and analyses the discrepancy of the different ranges. Li Ming, Chen Hongkai [6] makes an indoor similar model test, which combined with practical engineering examples, to study the destructive rules and the ultimate bearing capacity of the surrounding rock and the support structure under the state of the initial lining thickness reducing.

Although there are many researches of insufficient lining thickness and cavity, which only focus on the analysis of the single detect on tunnel safety, the research which focus on the analysis of the combination model of two or more detects are also rare. This article establishes the corresponding computational model depending on the insufficient lining thickness and cavity which are on different position and degree, and analyze the all kinds of situation on the tunnel deformation.

## 2. The Selection Model Parameter

Selecting a tunnel section is for the study of this article. The section, a two-lane tunnel section, uses the support structure in Figure 1: the IV Grade surrounding rock is used for the section, according to Specification Design of the Highway Tunnel (JTGD70-2004) [7] 12cm C20 shot-crete is used for tunnel initial support, 35cm C25 con-crete is used for the second lining and inverted arch. The tunnel span is 11.7m.

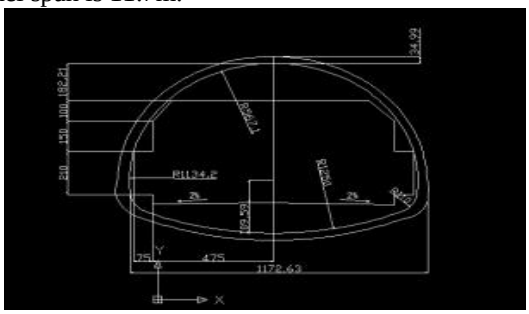

**Figure 1. Sectional view of tunnel support structure**

The physical - mechanical indicators of the IV grade sur-rounding rock and the concrete surrounding rock of the C20, C25 lining materials are shown in following Table 1 and Table 2.

**Table 1. The physical - mechanical indicators of the IV grade surrounding rock**

| Severe γ (KN/m3) | Elasticity modulus E(GPa) | Poisson's ratio μ | Angle of internal friction φ(°) | Cohesion C (MPa) |
|---|---|---|---|---|
| 23 | 1.3 | 0.35 | 39 | 0.7 |

**Table 2. The physical - mechanical indicators of the concrete surrounding rock**

| Name | Strength grade | Elasticity modulus (GPa) | Poisson's ratio | Severe (KN/m3) | Designed thickness (cm) |
|---|---|---|---|---|---|
| Initial support | C20 | 21 | 0.2 | 22 | 12 |
| Second lining | C25 | 29.5 | 0.2 | 25 | 35 |
| Inverted arch | C25 | 29.5 | 0.2 | 25 | 35 |

## 3. Numerical Simulation Analyses

### 3.1. The Insufficient Lining Thickness Degree and Location Selection

Based on the "formation - Structure" method, this article makes calculations for the tunnel model by the geotech-nical and tunnel finite element analysis software. Sec-ondary lining uses beam element to simulate, and 3 times tunnel span which is 33m is used for surrounding rock. According to Technical Specification of the Highway Tunnel Maintenance (JTG H12-2015) [8] , the k which is the ratio of the actual thickness and the designed thick-ness of the lining will indicate the insufficient thickness degree, it is divided into three grades: k≤1 / 2,1 / 2 <k≤2 / 3, k> 2/3, so this article takes 30cm, 20cm and 10cm three levels for the second lining thickness in the model. The quantitative indicators specification of the cavity are not yet come out, according to previous research, this article uses semi-circular to simulate, radius of cavity is 0.5m, the position were taken on the arch crown, haunch and arch springing.

### 3.2. The Simulation Analysis of Insufficient Lining Thickness

This calculation model just simulates the different degree of insufficient thickness of each lining position, and ex-tracts the maximum (minimum) displacement on X, Y direction as shown in Table 3:

**Table 3. The different degree of insufficient thickness of each lining position on the X direction**

| Position | Degree | | | | | |
|---|---|---|---|---|---|---|
| | k>2/3(30cm) | | 1/2<k≤ 2/3(20cm) | | k≤1/2(10cm) | |
| | MAX | MIN | MAX | MIN | MAX | MIN |
| Arch crown | 1.392 | -1.392 | 1.392 | -1.392 | 1.392 | -1.392 |
| Haunch | 1.392 | -1.393 | 1.393 | -1.393 | 1.395 | -1.394 |
| Side wall | 1.391 | -1.393 | 1.391 | -1.393 | 1.390 | -1.393 |

**Table 4. Lining various parts of the varying degrees of displacement in the Y direction due to thick**

| Position | Degree | | | | | |
|---|---|---|---|---|---|---|
| | k>2/3(30cm) | | 1/2<k≤ 2/3(20cm) | | k≤1/2(10cm) | |
| | MAX | MIN | MAX | MIN | MAX | MIN |
| Arch crown | 6.300 | -6.245 | 6.300 | -6.245 | 6.300 | -6.245 |
| Haunch | 6.300 | -6.243 | 6.301 | -6.240 | 6.303 | -6.237 |
| Side wall | 6.300 | -6.244 | 6.302 | -6.242 | 6.304 | -6.239 |

### 3.3. The Simulation Analysis of the Combination of Cavity and Insufficient Lining Thickness

The calculation model adapts to the different degree of insufficient thickness of each lining position combining with 0.5m radius cavity, and extracts the maximum and minimum displacement of the different combination po-sitions, as follows:

**Table 5. The combination of cavity and insufficient lining thickness degree on X direction displacement**

| 0.5m Cavity | The displacement on different degree（mm） | | | | | |
|---|---|---|---|---|---|---|
| | k>2/3(300) | | 1/2<k≤ 2/3(200) | | k≤1/2(100) | |
| | MAX | MIN | MAX | MIN | MAX | MIN |
| Arch crown | 1.464 | -1.462 | 1.465 | -1.463 | 1.466 | -1.464 |
| Haunch | 1.753 | -1.446 | 1.752 | -1.446 | 1.752 | -1.447 |
| Arch springing | 1.209 | -1.344 | 1.209 | -1.344 | 1.208 | -1.344 |

**Table 6. The combination of cavity and insufficient lining thickness degree on Y direction displacement**

| 0.5m Cavity | Degree | | | | | |
|---|---|---|---|---|---|---|
| | k>2/3(30cm) | | 1/2<k≤ 2/3(20cm) | | k≤1/2(10cm) | |
| | MAX | MIN | MAX | MIN | MAX | MIN |
| Arch crown | 6.300 | -5.947 | 6.301 | -5.940 | 6.302 | -5.933 |
| Haunch | 6.305 | -6.420 | 6.306 | -6.417 | 6.307 | -6.414 |
| Arch springing | 6.523 | -6.638 | 6.525 | -6.636 | 6.527 | -6.634 |

In order to compare the two calculation results, according to the X, Y direction displacement, the line chart is made as follows:

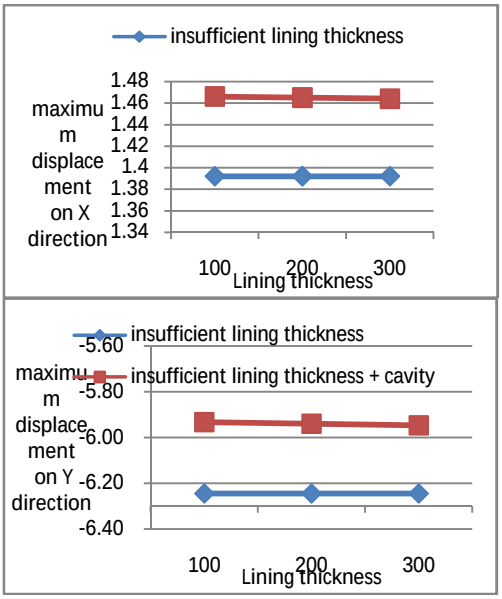


**Figure 2. Comparison of the two results on arch crown**

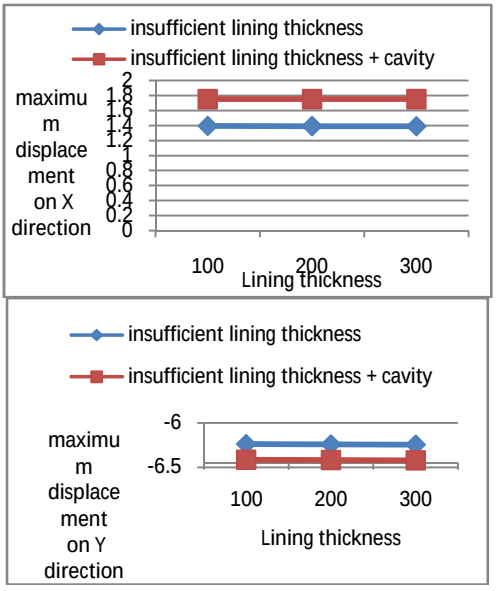


**Figure 3. Comparison of the two results on haunch**

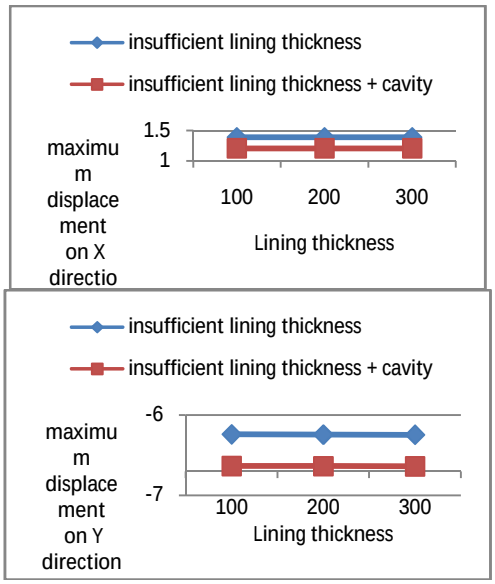


**Figure 4. Comparison of the two results on arch springing**

## 4. Conclusions

(1) In a single model of the insufficient lining thickness, the same parts of the different degrees of insufficient lining thickness has little effect on deformation; the same little effect on deformation occur on different parts of the same degree of deformation of insufficient lining thickness .

(2) In the model of insufficient lining thickness combine with cavity, the maximum (minimum) horizontal displacement is on the haunch, and the maximum (minimum) vertical displacement is on the arch springing.

(3) Comparing the two models, it's found that: on the arch crown, combined model is larger than single model on the maximum horizontal displacement and smaller on the minimum vertical displacement; on the haunch, the combined model is larger both on the maximum (minimum) horizontal and vertical displacement. On the arch springing, combined model is smaller on the maximum horizontal displacement and larger on the minimum vertical displacement, which is opposite on the arch crown.

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