Numerical Analysis for Selection of New Arch Framework Structures Made of Precast Block Materials for Highway Slope Protection

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Abstract: Arch framework structure is one of the common forms of highway slope protection in actual projects, and the rapid development and wide application of new type arch framework structures made of precast block material are for their convenient construction and environmental protection. The article selects two typical arch shaped framework structures made of traditional mortar rubble, and precast block material over mortar foundation respectively. According to actual structure sizes, finite element analysis models were built to calculate and analyze the displacement and stress of two structures under same vertical loading pressure. The results of the numerical analysis and laboratory test results show that, the difference of the displacement between the two structures is small, and the displacement of new structure is a little bigger. The stress of new structure is significantly less than traditional structure. The new type structure of precast block material over mortar foundation possesses better over-all performances among the chosen two structures and can be used widely.

Keywords: Highway slope protection; Arch framework; Structure selection; Numerical analysis

INTRODUCTION

The soil slope protection structures of the highway are prone to erosion, slump, collapse and other damages under the environment of rain, which affect the stability and durability of subgrade slope.

Specifications for Design of Highway Subgrades in China stipulates that the slope structure that is easily damaged by natural factors should select appropriate protective measures based on the economic and technical comparison, accounting for climatic conditions, rock and soil properties, slope height, slope gradient, hydrogeological conditions, construction conditions, environmental protection, soil and water conservation requirements.

The role of skeleton slope protection is to support and split the slope, eliminating the gradient influence each other within the wider range of impact. Arch-type framework slope protection is one of the most commonly used forms of slope protection for highway embankment. Arch-shaped skeleton on the stability of soil is better, because the arch itself on the slope of the soil has a certain role in supporting the reinforcement.

Domestic scholars mainly focus on the stability of subgrade slope, while neglecting the influence of the stability of slope protection skeleton structure on subgrade slope. In 2012, Li Long etc. used Mohr-Coulomb model to explore the skeleton slope protection in the loess embankment, and the study shows that the structural stability of slope protection will affect the overall stability of slope.
stability. The stability of the slope protection structure is the necessary factor for the long-term stability of the subgrade slope. However, at present, the research literature mainly focuses on the construction technology, quality management technology and ecological protection of skeleton structures. And the foreign scholars mainly focus on the protection and mechanism of ecological restoration in slope protection, stability analysis of the slope itself, and for the stability of the skeleton structure of the slope protection itself is less. In the past two years, the author research team has carried out numerical analysis and model test to study the skeleton structure and stability of highway subgrade slope protection.

In recent years, precast concrete technology, prefabricated construction method and precast concrete structure system are popularized, and the precast component technology is conducive to the implementation of civilized construction, waste recycling and environmental protection. And sustainable development ideas have been rapid development and application. In this paper, the traditional pure mortar stone arch structure and new precast block material arch structure are selected for study, and numerical analysis model is established to analyze the mechanical response.

1. Arch Framework Slope Protection Structures

In this paper, two kinds of materials are used to combine the arch structure: the traditional arched skeleton structure and the new arched skeleton structure (hereinafter referred to as the traditional structure and new structure). Two structures have the same size: 6.514m high, 7.000m wide, 11.360m long, slope grade is 1:1.5, and slope length is 11.112m, and 26cm thick common cement concrete pavement is arranged at the top of the roadbed, and 2 rows and 3 columns arched skeleton is arranged on the slope protection. The difference between the two structures is the material of the skeleton structure. The traditional structure skeleton is made of 30cm thick mortar. The new modern structure is made up of 20cm thick mortar foundation, and 10cm thick flat seam precast block surface layer. Arch-shaped skeleton revetment front dimensions see Figure 1.

The key points are as follows: P1-P6, which represent the top of the slope P1, top of the arch in first row P2, bottom of the arch in first row P3, top of the arch in second row P4, bottom of the arch in second row P5, slope toe P6. Select the key slope line 2-2 through points P3, P5, P6. Distribution diagram of
key points, key slope line, key profile is shown in Fig 2.

2 Numerical Model Analysis
2.1 Conditions and Parameters of Numerical Model Analysis

a. Traditional structure  

b. Modern new structure  

Figure 3. Grid graph for numerical model.

As actual arched frame size of the project, numerical model is established using ANSYS11.0 software for analysis, and divided grid cell type is solid45, adopting symmetrical structure. Traditional structure and new structure numerical model network division, see Figure 3.

The boundary conditions of load: the top surface pressure is 0.7 MPa, the center plane and the side surface are symmetric boundary planes, the X, Y and Z directions displacement of the bottom surface are all restrained and the X direction displacement of the opposite surface of the center plane is restrained. The gravitational acceleration of the material, using the glue boolean operation bonding the interface between different materials. The material parameters of the model see Table 1.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Elasticity Modulus (MPa)</th>
<th>Density (kg/m³)</th>
<th>Poisson Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precast block</td>
<td>40</td>
<td>1500</td>
<td>0.35</td>
</tr>
<tr>
<td>Concrete</td>
<td>28000</td>
<td>2360</td>
<td>0.17</td>
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<tr>
<td>Pavement</td>
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<td>2430</td>
<td>0.15</td>
</tr>
<tr>
<td>Mortar rubble</td>
<td>7000</td>
<td>2300</td>
<td>0.2</td>
</tr>
</tbody>
</table>

2.2 Numerical Simulation Results and Analysis
2.2.1 Vertical Displacement Analysis

Figure 4. Vertical displacement distribution of key points.  

Figure 5. Vertical displacement distribution of key slope line.
For the two kinds of arch structure, under the same stress conditions, the key points, the key slope vertical displacement distribution are shown in Figure 4 and Figure 5. In general, the vertical displacements of the key points and the key slope lines are nonlinearly reduced with the increase of the sloping distance from the top of the slope, and the deceleration of the displacement from the top to the bottom is fast to slow. The maximum displacement of the key points, and the maximum difference of the vertical displacement of key slope line of the two structures are all at the top of the slope P1. The maximum displacement is 41.6mm, and the maximum difference is 6.1mm. The vertical displacement of the new structure is slightly larger than traditional structure.

### 2.2.2 Lateral Displacement Analysis

![Figure 6. Lateral displacement distribution of key points.](image1)

![Figure 7. Lateral displacement distribution of key slope line.](image2)

For the two arch structures, the horizontal displacement (horizontal line parallel to the cross section of the subgrade) of the key points and key slope under the same stress condition is shown in Figure 6 and Figure 7. The horizontal displacement of the key points and the key slope shows positive and negative changes, which indicates that the lateral convex deformation occurs in the middle part of the slope surface. The horizontal displacement maximum appears in the upper row of the key point P2, indicating that P2 is the most unfavorable position of horizontal displacement. The maximum horizontal displacement of the key points and the key horizontal line are 16.2mm and 12.5mm respectively. And the maximum difference is 3.7mm and 3.5mm respectively. The horizontal displacement of the new structure is slightly larger than traditional structure.

### 2.2.3 Equivalent Stress Analysis

![Figure 8. Equivalent stress distribution of key points.](image3)

![Figure 9. Equivalent stress distribution of key slope line.](image4)
For the two arch structures, the equivalent stress (horizontal line parallel to the cross section of the subgrade) of the key points and key slope under the same stress condition is shown in Figure 8 and Figure 9. In general, the equivalent stress of each arch key points is wavy line, and the stress at the top of the arch is in the trough, and the stress at the foot of the arch is at the crest, which indicates that the arch foot location is in a disadvantageous position. The equivalent stress on two key slope line has a wavy line shape, and the stress at the arch foot locate in the trough, indicating that the adjacent arch has the stress offset phenomenon at the junction of the arch foot. The equivalent stress of the new structure is larger than that of the traditional structure except for the top key point P1. The equivalent stress of the new structure is smaller than that of the traditional structure, and the maximum equivalent stress of the key points and key slope is 14.3Mpa and 14.5Mpa respectively, and the maximum difference reached 10.4Mpa and 8.8Mpa respectively. The equivalent stress of the new structure is obviously smaller than that of the traditional structure on whole.

3 Laboratory Model Test

Through constructing miniature test model at the ratio of 0.25, the change law of displacement and stress at different key points in the framework slope protection structure were tested, the bearing capacity mechanism of the mortar framework slope protection structure was discussed under vertical loading. Loading vertical stress on pavement, solid model dimensions and photos are shown in Fig 10.

The results of the laboratory test show that, upper part of the skeleton model subsidence, lower part of the skeleton model convex, the result is substantially same as lateral displacement numerical simulation analysis. The strain at the top of the arch is less than the strain at the foot of the arch in each arch skeleton, which indicates that the arch foot location is in a disadvantageous position, the result is same as equivalent stress numerical simulation analysis. Because of the strain and displacement monitoring on the laboratory model
surface, the results are not an exact same with numerical simulation, it still proves the correctness of the numerical simulation results and analysis to a certain degree.

4 Conclusion
In this paper, the traditional pure mortar stone arch structure and new precast block material arch structure are selected for study, and numerical analysis model is established to analyze the mechanical response. The vertical displacement, horizontal displacement and equivalent stress are compared and analyzed, and the conclusions as follows:

(1) Under the same mechanical conditions, the vertical displacement and horizontal displacement of the new structure at the key points and the key slope are slightly larger than those of the traditional structure. The vertical displacement is mainly concentrated in the range of the top of the slope to the top of the 1st row arch. Transverse lateral convex deformation arises in the central slope, the future may consider further strengthening of these areas.

(2) Under the same mechanical conditions, the equivalent stress of the new structure at the critical points and the critical slope is obviously smaller than that of the traditional structure. The arch feet of the two structures are in the stress unfavorable position. The equivalent stress of the arch on the two columns is smaller due to the synergistic effect of the adjacent arch.

(3) The results of the laboratory test on lateral displacement and equivalent stress have same regularity with the results of the numerical simulation analysis, it some degree prove the correctness of the numerical simulation results and analysis.

The new type structure of precast block material over mortar foundation possesses better over-all performances among the chosen two structures and can be used widely.

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REFERENCES


