Influence of the Reservoir Position on Sponge Slope Stability

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Abstract. Sponge slopes have received increasing attention due to their unique ecological advantage. Based on the three-dimensional numerical calculation model, the paper explores the influence of the position of the reservoir on the safety and stability of the slope and compares the variation characteristics of the sliding displacement and stress field of the slope. The results show that when the reservoir is built below the slope foot or at the slope top, the disturbance is relatively small, and the maximum displacement of the slope is smaller. Shear stress concentration occurs near the wall of the reservoir, and it increases and then decreases as the height of the reservoir increases. Besides, the maximum principal stress appears near the reservoir wall and the maximum principal stress decreases as the position of the reservoir increases.

1. Introduction

Sponge slope is quite significance for the ecological vegetation protection and environmental technology restoration under the multi-disciplinary guidance[1]. Sponge slope can effectively improve the utilization rate of water resource, and provide the good living environment for the vegetation, to realize the ecological environment protection. It is a very effective ecological protection technology for the slope stability. Compared with the general slopes, the sponge slope is safer and more ecological. The construction of the sponge slope can further reduce the occurrence probability of regional soil and water loss, which is conducive to improve the environmental conditions and the slope stability. Therefore, in the process of urban eco-system construction, it is necessary to construct the sponge slope by the advantages of “sponge technology”.

The general designs pay more attention to engineering effects, and lack the awareness of ecological protection. The construction of ecological slope pays more attention to the surrounding environmental protection, which is also a very effective mean for the slope protection[2,3]. In recent years, relevant laws and regulations require the implementation of ecological vegetation restoration in China[4]. With the continuous development of highway construction, especially for the ecological protection of highway engineering slope, the relevant treatment work has been carried out, and the ecological restoration technology along the highway slope has been continuously improved. Donald et al.[5] systematically summarized the greening methods for the existing slope, and further explored the impact of the green ecosystem on slope stability[6,7].
In the construction of sponge city, Shen[8] took the rainwater recycling project of Haihua island in Danzhou as an example to introduce the application practice of a reservoir. According to the construction theory of a sponge city in Germany, Xu et al.[9] carried out the improvement construction in a community. Ren et al.[10] proposed to use a water cellar to collect rainwater and irrigate green plants beside the road. In the Guizhou karst mountain area, Fan et al.[11] carried out the research on rainwater reuse, and proposed that rainwater can be collected through the slope surface, and the rainwater can be introduced into the water cellar to irrigate crops through ditches. In the highway construction project, Zhang et al.[12] proposed to use water cellar, surface reservoir, and other devices to collect and store rainwater, providing the water source for agricultural crop irrigation.

In the process of sponge slope construction, the location of the reservoir will seriously affect the safety and stability of the slope. At present, there are few researches on the influence of reservoir location on slope safety. Based on the strength reduction theory of finite element and considering the geological and hydrogeological conditions, some scholars have analyzed the influence of the reservoir on the safety factor of slopes[13-15]. Therefore, through the three-dimensional numerical method, the slope model was established to study the distribution characteristics of the displacement and surrounding stress field of the reservoir, which can provide corresponding technical reference for a reasonable selection of reservoir location on the sponge slope.

2. Numerical model
To study the influence of the reservoir constructing in the slope, a three-dimensional calculation model was established, as shown in Figure 1 and Figure 2.

In the process of numerical calculation, the front, back, left, right, and bottom boundaries the slope model were fixed. The upper boundary of the model was set as a free boundary. The displacement of grid nodes (X= 0 and X= 40) in the X direction was fixed in the calculation model, and the displacement of all grid nodes in the Y direction was fixed, and the displacement of all grid nodes (Z = 0) was fixed. The model was shown in Figure 2 after boundary constraint conditions were applied.

The division of the model grid is the premise of FLAC3D numerical simulation calculation. It requires that the three-dimensional model grids can be connected to form a continuous and complete geometric body, and the ratio of mesh division should be ensured consistently. In this slope model, a total of 40960 elements and 45441 nodes were generated.

The model material adopts the Mohr-Coulomb model. The physical and mechanical parameters of the slope are shown in Table 1.

| Name         | Density / kg/m³ | Elastic modulus | Cohesion / kPa | Friction angle | Tensile strength | Poisson's ratio |
|--------------|-----------------|-----------------|----------------|----------------|------------------|-----------------|
3. Analysis of the calculation results
This paper simulates the reservoirs construction at different positions in the slope, and monitors the
displacement of the slope foot (measuring point 1), the slope middle (measuring point 2), and the slope
top (measuring point 3), to obtain the law of displacement changes. Furthermore, the impact of
reservoir construction at different locations on stress field is explored.

### 3.1. Displacement field
The displacement contours of the slope with the reservoirs at different positions are shown in Figure 3.
As can be seen from Figure 3, when the vertical distance from the reservoir top to the slope foot is 0 m,
the maximum displacement of the slope body occurs at the upper part of the slope foot; when the
vertical distance from the reservoir top to the slope foot is 2 m, the maximum displacement occurs in
the upper part of the reservoir; when the position of the reservoir moves up gradually, the maximum
displacement occurs at the slope foot.

![Figure 3. Contour of displacement with different positions of the reservoirs (unit: cm)](image)

The displacement curves of the three measuring points are shown in Figure 4. It can be seen that as
the reservoirs positions rise gradually, the maximum displacement of the slope body shows the
tendency to increase and then decrease. When the vertical distance from the reservoir top to the slope
foot is 2 m, the displacement of the slope is the largest, thus the excavation and construction of the
reservoir at this position will cause greater disturbance to the slope deformation.

|          | /GPa | /Pa |
|----------|------|-----|
| Silty clay| 2000 | 0.015 | 15 | 20 | 0 | 0.3 |
| C30 concrete | 2400 | 30.0 | - | - | - | 0.2 |
When the reservoir is constructed below the slope foot or at the slope top, the disturbance caused by the reservoir construction on the slope is smaller, that is the displacement of the slope body is smaller. Based on the Figure 4, it can be seen that when the reservoir is excavated at the slope foot, in the middle of the slope, and at the slope top, the displacements of the monitoring points eventually tend to be stable.

3.2. Shear stress field

The shear failure often occurs inside the slope, which is the main failure mode. Instability failure often occurs along the sliding surface in the slope, so the slope stability can be analyzed based on the shear stress field.

The contours of the shear stress are shown in Figure 5. When the distance from the reservoir top to the slope foot is 0 m, the shear stress of the slope is concentrated around the reservoir, and the shear stress increases with the depth of the slope, and the gradient of increasing stress value is consistent.
By comparing the shear stress of the slope with the reservoirs excavated at different positions, it is found that the shear stress concentration appears around the reservoir wall, which shows the tendency to increase and then decrease with the reservoir positions. When the distance from the reservoir top to the slope foot is 2 m, the maximum shear stress near the reservoir wall is 0.3 MPa. When the reservoir is built at the slope top, the shear stress near the reservoir wall is the smallest value 0.06 MPa.

3.3. Principal stress field

Figure 6 shows the contour of the maximum principal stress after the reservoir construction. After the reservoir is excavated and constructed, stress concentration occurs around the reservoir wall, and the maximum principal stress appears near the reservoir wall. It shows that the maximum principal stress appears around the wall of the reservoir, and the maximum principal stress value decreases with the reservoir position rising. When the distance from the reservoir top to the slope foot is 0 m, the maximum principal stress near the reservoir wall is 0.6 MPa. When the reservoir is constructed at the slope top, the maximum principal stress around the pool wall is about 0.1 MPa.
4. Conclusion

The numerical models of the slope with the reservoir at different positions are established, focusing on the impacts of the reservoir construction on the displacement and the stress field, the main conclusions are as follows:

(1) Reservoir construction at the slope foot or the slope top, respectively, has less disturbance to the slope stability. In the cases, the maximum displacement induced by the reservoir construction is relatively small, and the maximum displacement occurs at the slope foot.

(2) By the shear stress field of the slope, it is found that the shear stress concentration appears around the reservoir wall, and it increases and then decreases with the reservoir position rising. When the distance from the reservoir top to the slope foot is 2 m, the shear stress near the reservoir wall indicates the maximum value of 0.3 MPa.

(3) The maximum principal stress appears near the reservoir wall after the reservoir construction, also the stress concentration will occur around the reservoir wall. Besides the maximum principal stress around the reservoir wall will decrease with the reservoir position rising.

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