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To cite this article: Yi Xu *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **455** 012122

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# The Study of Slope Protection with Gravel-Polymer Composite Porous Material

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**Abstract.** In this study, strength reduction method, steady state analysis and transient analysis are used to simulate and compare the stability and permeability characteristic of bank slope in three different states: natural, slope protection with concrete and slope protection with gravel-polymer composite material. The result show that the slope with protective surface is more prone to shallow shear failure than the bank slope in natural state and their stability is reduced. For the bank slope of slope protection with gravel-polymer composite material, the appropriate thickness of the surface layer should be selected to give full play to the bending performance. In terms of permeability characteristics, slope protection with gravel-polymer composite material has good permeability and it is more difficult to destroy by percolation when the water level drops rapidly.

**keyword:** Slope protection with gravel-polymer composite material, Stability analysis, Permeability characteristics

## 1. Introduction

As a new type of slope protection, many scholars have made researches on the slope protection with gravel-polymer composite material and obtain lots of achievements in recent years. However, most researches focus on the improvement of ecological environment, scour resistance and corrosion resistance<sup>[1]-[3]</sup>. It lacks quantitative analysis that the excellent performance of slope protection with gravel-polymer composite material in the engineering application<sup>[4]</sup>.

In order to quantitatively analyze the effect of slope protection with gravel-polymer composite material in engineering, this study analyzes the slope stability and permeability characteristics by establishing a numerical model of bank slope. SRM (Strength Reduction Method) based on finite element analysis is used to analyze the stability of bank slope and the internal force of the structure<sup>[5]</sup>. Then the results are compared with the slope protection with ordinary concrete under the same conditions. The steady state analysis and transient analysis are used to analyze the permeability characteristics under the conditions of river level in stable state and rapid fall of river level<sup>[6]</sup>.

## 2. Numerical Model Building

According to the data of bank slope, the slope numerical model is established as shown in figure 1. Its height is 16 m, whose width is 39 m, and the slope gradient is 37.5 °. The soil mass of bank slope is divided into three layers, from the top to the bottom are respectively filling, muddy soil and silty soil, among which the thickness of filling is 6 m, the thickness of muddy soil is 4 m and the thickness of silty soil is 6 m. The physical and mechanical parameters of each soil layer are shown in table 1.



The slope protection is directly laid on the surface of the bank slope. In this research, slope protection, simulated by the beam element, is composed of gravel-polymer composite material or concrete. The section is a solid rectangle, and the thickness of the surface course is 20 cm per unit width. The parameters of structural materials are shown in table 2.

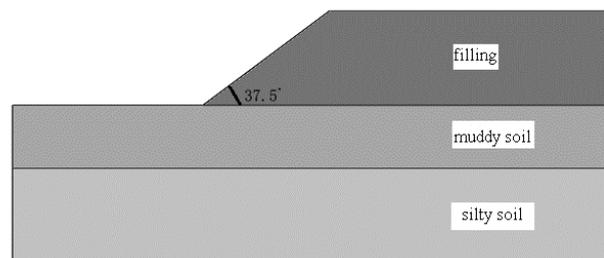
According to hydrological data of the river, the river is on the left of the bank slope. The river level is 13 m, and the groundwater level is 15 m. Therefore, the node pressure head of 13 m is set on the finite element of riverbed and slope as the river level, and the right boundary of the slope is set as the seepage surface of river. On the right of the slope, the node pressure head of 15 m is set as the groundwater level, subsequently, the riverbed and slope are set as the seepage surface of groundwater.

**Table 1.** Physical and mechanical parameters of each soil layer.

soil layer	Constitutive model	k(cm/s)	E(kPa)	$\gamma$ (kN/m <sup>3</sup> )	C(kPa)	$\varphi$ (°)	$e_0$
filling	MC	$1.00 \times 10^{-4}$	6000	18	12	14	0.855
muddy soil	MC	$4.0 \times 10^{-5}$	3200	17.3	10	14.1	1.149
silty soil	MC	$3.0 \times 10^{-6}$	12000	18.3	9	22.4	0.874

**Table 2.** Material parameters of slope protection structure.

structure material	$\sigma_{bc}$ (MPa)	$\sigma_{bb}$ (MPa)	E(MPa)	$\gamma$ (kg/m <sup>3</sup> )	k(cm/s)	porosity
gravel-polymer composite material	5.81	2.91	428.2	1532	1.8	35.50%
concrete	14.3	1.43	$3.0 \times 10^7$	2350	$1.0 \times 10^{-8}$	5%



**Figure 1.** Numerical model of bank slope.

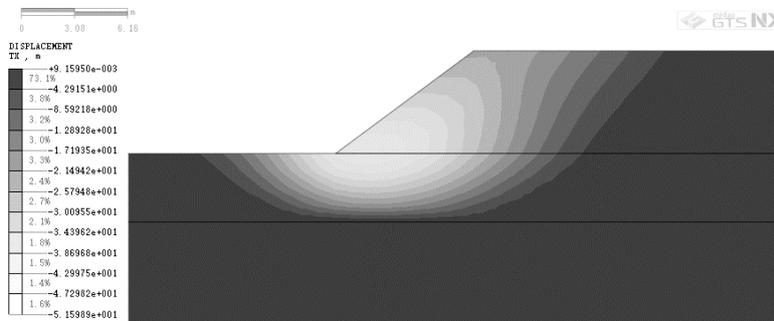
### 3. Stability Analysis of Bank Slope

In order to study the stability of the slope under the action of slope protection with gravel-polymer composite material, the slope stability analysis and the stress analysis of different kind of protection structures are carried out for natural state, gravel-polymer composite material and concrete respectively, and the results are compared<sup>[7]</sup>.

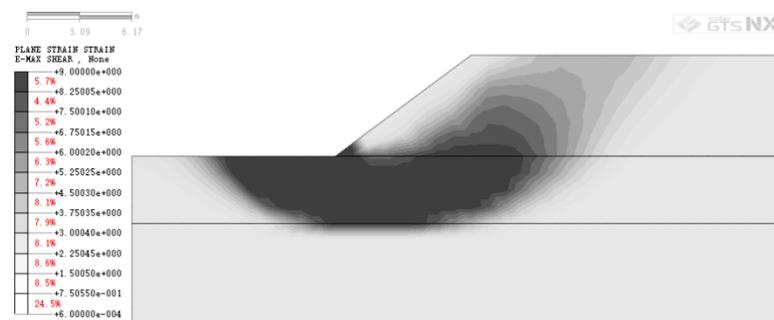
#### 3.1. Stability Analysis of Bank Slope in Natural State

According to SRM analysis, it is 2.2156 that the safety factor of slope stability under natural state. In other words, the slope is stable. The nephogram of horizontal displacement of bank slope under natural state calculated by this method is shown in figure 2. It can be seen from figure 2 that the soil mass at the foot of the bank slope has a large displacement. That is to say that the slope foot is most prone to horizontal sliding. In addition, the potential slip surface can be seen clearly in the figure, and the bottom of the slip surface is located at the boundary of muddy soil and silt. The nephogram of maximum shear strain of bank slope under natural state is shown in figure 3. From the figure, the plastic deformation

area is developed in the muddy soil under the slope foot, and has a tendency of running through the slip surface.



**Figure 2.** Nephogram of horizontal displacement of bank slope under natural state.

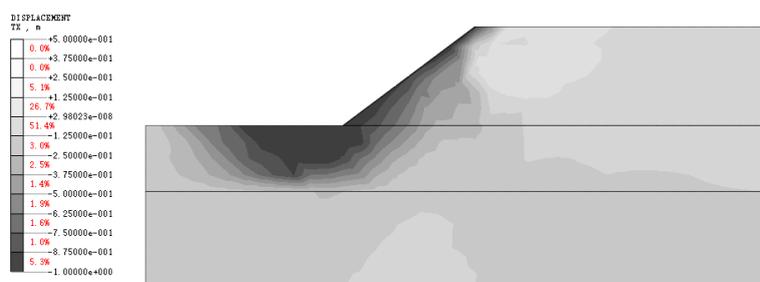


**Figure 3.** Nephogram of maximum shear strain of bank slope under natural state.

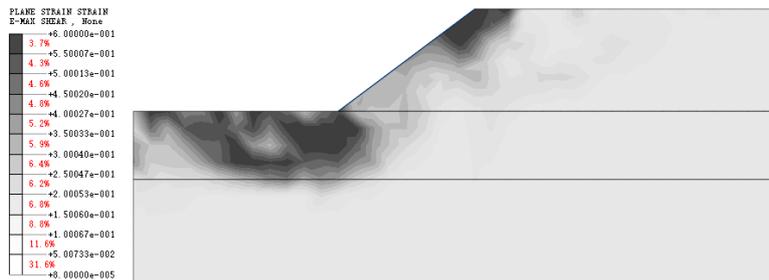
### 3.2. Analysis of Polymer Gravel Mixture Revetment

After calculating the stress and displacement of the natural bank slope, clearing the displacement and keeping the stress state already calculated and activating the polymer gravel protective face unit to simulate the bank slope protected by the polymer gravel protective face, meanwhile, we use strength reduction method to analyze its stress and stability.

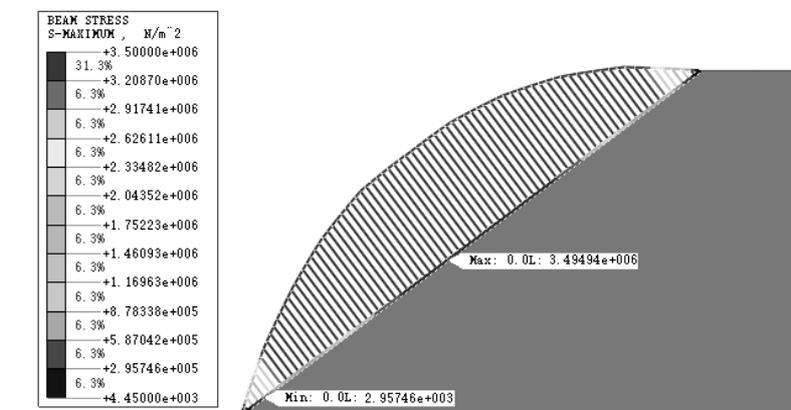
We have calculated the safety factor of slope stability of those slopes which have laid the polymer gravel protective facing is 1.067. At present, the horizontal displacement and the maximum shear strain cloud picture of the bank slope are shown in figures 4-5. It can be seen from figure 4 that the horizontal displacement of the soil at the bed surface of slope toe and below the revetment’s protective face is the most significant due to the gravity of the protective face structure after laying the polymer gravel mixture revetment. It can be seen from Figure 5 that the plastic deformation area at the foot of slope and the top of slope is obviously developed, but the transfixion of the slip surface has not formed yet.



**Figure 4.** Cloud picture of horizontal displacement of polymer gravel mixture revetment.



**Figure 5.** Cloud picture of maximum shear strain of polymer gravel mixture revetment.



**Figure 6.** Maximum bending stress distribution of polymer gravel mixture panel.

The combined maximum bending normal stress distribution on the polymer gravel mixture revetment is shown in figure 6. The maximum bending stress is 3.495 mpa, which is greater than the bending strength (2.19 mpa) of polymer gravel mixture material. Therefore, it is necessary to reduce the bending stress of the surface layer by changing the thickness of the surface layer or cooperating with other protection means under this simulation condition.

**Table 3.** Maximum bending normal stress of surface layer with different thickness.

No	thickness/cm	Maximum bending normal stress/MPa
1	25	3.422
2	20	3.495
3	15	4.415
4	10	6.147
5	5	7.287

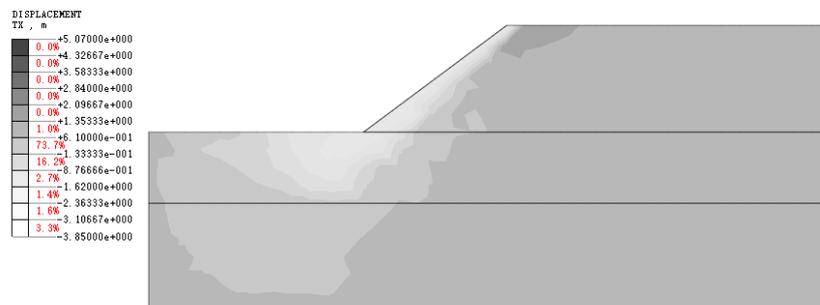
The maximum bending normal stress (combination) of the revetment surface under different thickness is shown in table 3. It can be seen from table 3 that in general, with the increase of the thickness of surface layer, the maximum bending normal stress of the surface layer gradually decreases. It is noteworthy that when the thickness of revetment surface layer is less than 20 cm, the maximum bending stress of the surface layer decreases obviously with the increase of the thickness of surface layer, while when the thickness of the surface layer is greater than 20 cm, the maximum bending stress of the surface layer slightly decreases with the increase of the thickness of surface layer. And this is because the mass of the surface layer increases with increasing thickness, which makes the settlement deformation of the soft soil layer increase under the high additional stress, and causes the local bending deformation of the panel to increase, thus the increased bending stress offsets the reduction effect of the bending stress

caused by the increase of the thickness. Therefore, the thickness of the revetment's surface layer should not be too large in order to give full play to its flexural performance.

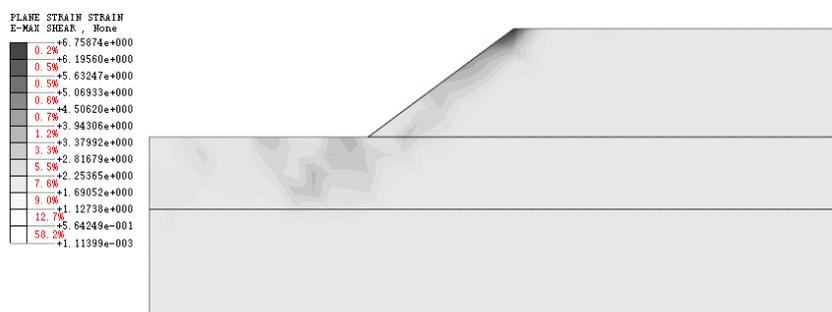
### 3.3. Analysis of Concrete Revetment

The same method is used to analyze the stress and stability of the slope under the action of concrete revetment, and the slope stability safety factor of the slope with concrete protective face is calculated to be 1.096, that's to say the slope is in a stable state. At this time, the horizontal displacement cloud picture of the slope is shown in figure 7. It can be seen from the figure that the area with the largest deformation of the soil is transferred from the slope toe to the bottom of the bed surface. This is because the concrete protective face with the same thickness has greater mass than the polymer gravel mixture revetment and its force on the bed surface is greater. In addition, the stiffness of the concrete surface layer is far greater than the polymer gravel mixture material, so the force can be better transmitted to the bottom, rather than vertically downward.

The maximum shear strain cloud picture of the concrete revetment is shown in figure 8. It can be seen from the figure that under the action of concrete protective face, the maximum shear strain of the slope occurs at the top of the slope, the plastic deformation area extends downward from the top of the slope, the potential slip surface develops along the slope, and the development position is shallow, therefore laying concrete protective face is liable to cause the shallow layer of the slope to slip driven by the protective face structure. This is mainly because the stiffness of the concrete panel is too large to coordinate with the soil mass of the slope. In the practical engineering, the size of the revetment block can be appropriately reduced to improve the deformation adaptability of the concrete protective face structure and the slope.



**Figure 7.** Cloud picture of horizontal displacement of concrete revetment.



**Figure 8.** Cloud picture of the maximum shear strain of the concrete revetment.

Similarly, the stress analysis of the concrete surface layer shows that the maximum bending stress of the concrete surface layer is shown in figure 9. It can be seen from the figure that the maximum bending stress on the concrete panel is 1.92 mpa, which is greater than the flexural strength of the material given

in table 2. Therefore, in this case, thickness of the surface layer should be increased or material with higher bending strength should be selected.

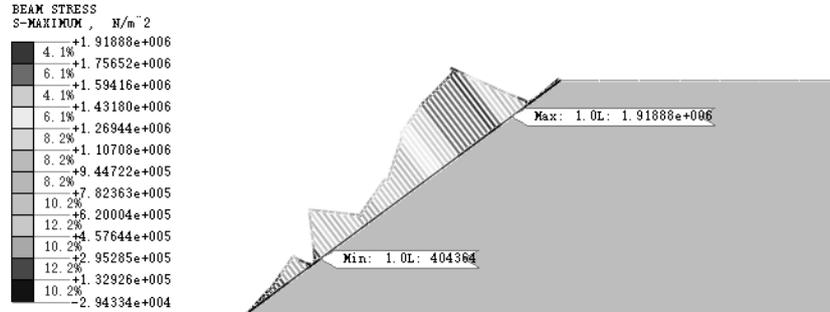


Figure 9. Maximum bending stress distribution curves of concrete panel.

According to the numerical analysis of the stability of bank slope under the action of polymer gravel mixture and concrete protective face, compared with the natural bank slope, the potential slip surface in the body of the revetment has moved up, and shear failure of the slope is more likely to occur along the shallow layer of the revetment after the protective face is laid. It can be seen from the soil layer and slope deformation that the deformation of the bank slope is relatively large due to the soft soil layer under the bank slope. In this case, the revetment surface layer may be damaged due to the excessive deformation. Therefore, in the practical engineering, size of a single surface layer should be reduced to prevent the local damage caused by the uneven deformation of the polymer gravel mixture revetment.

#### 4. Seepage Analysis of Slope under the Action of Revetment

##### 4.1. Analysis of Steady Seepage

In order to explore the influence of polymer gravel mixture material revetment on slope under the steady seepage, the steady seepage simulation study is carried out for the seepage characteristics of polymer gravel mixture material revetment<sup>[8]</sup>. Activate the polymer gravel mixture revetment structure and set nodal energy grade for steady-state analysis of seepage, and the total water head distribution in the polymer gravel mixture bank slope under the original water level is shown in figure 10. It can be seen from the picture that the water head of the polymer gravel mixture revetment decreases obviously, which shows that the polymer gravel mixture revetment has good water permeability.

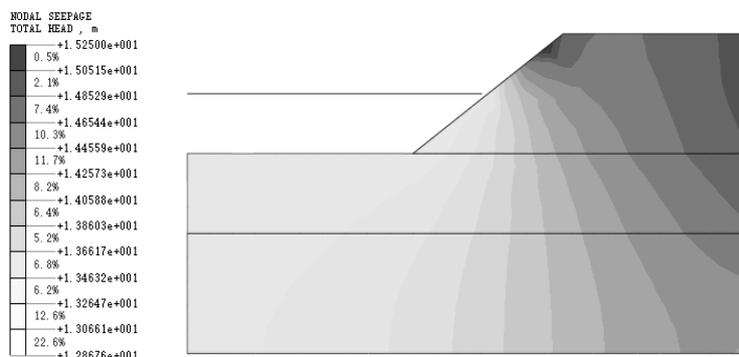
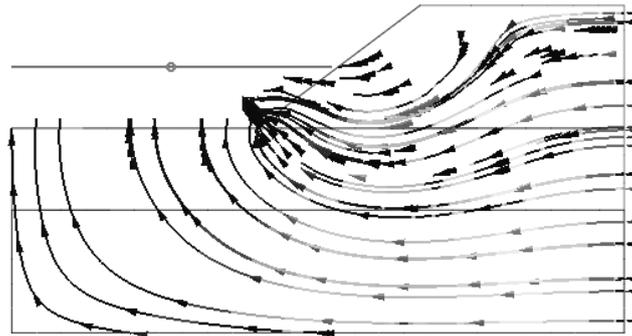


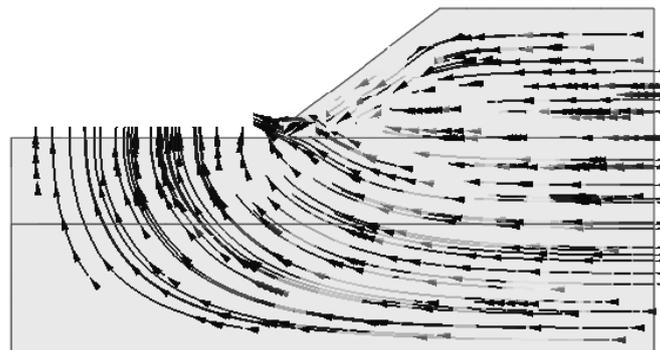
Figure 10. Total head of bank slope of polymer gravel mixture revetment at stable river level.

The seepage path of the polymer gravel mixture bank slope under the original water level is shown in figure 11. It can be seen from the picture that the seepage from the slope surface to the outside of the soil is not affected by the revetment, which shows that the good water permeability of the polymer gravel

material revetment will not block the seepage on the slope surface. Under the same conditions, the path of seepage in the concrete revetment is shown in figure 12. It can be seen from the figure that most of the seepage of the bank slope with the concrete protection layer is concentrated at the slope toe and the riverbed. The concrete revetment almost completely blocks the channel for the river to enter into. The seepage on the slope bypasses the revetment structure and infiltrate from the slope toe. Compare these two revetments, the polymer gravel material has obvious water permeability and good drainage on the slope, which guarantees the hydraulic connection between groundwater and river water.



**Figure 11.** Seepage path of polymer gravel mixture revetment at stable river level.



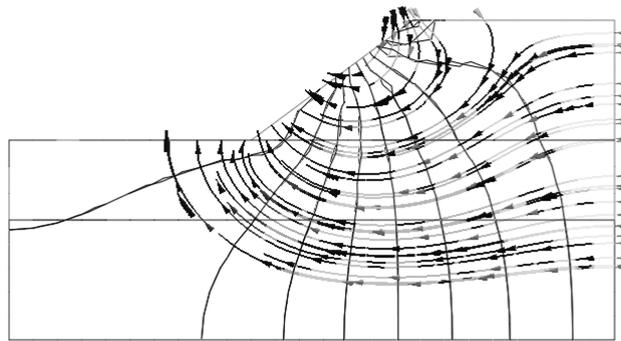
**Figure 12.** Seepage path of concrete revetment at stable river level.

#### 4.2. Transient Seepage Analysis

In order to understand the seepage change law in the bank slope when the water level changes rapidly and the influence of two kinds of slope protection surface layers on the seepage and stability in the bank slope, transient seepage is used to simulate the seepage change in the bank slope when the water level drops<sup>[9]</sup>. In order to view the analysis results by phases, the original water level, water level sudden drop and water level maintenance are respectively set up in three phases, of which the original water level stage adopts steady state analysis, the water level sudden drop and water maintenance stage adopts transient analysis, and the water level sudden drop stage is divided into two steps. The water level dropped by 1.5 m within 72 hours, and the final water level was 11.5 m. The lowered water level was maintained at 11.5 m for two months, and the seepage change in the bank slope after two months was analyzed.

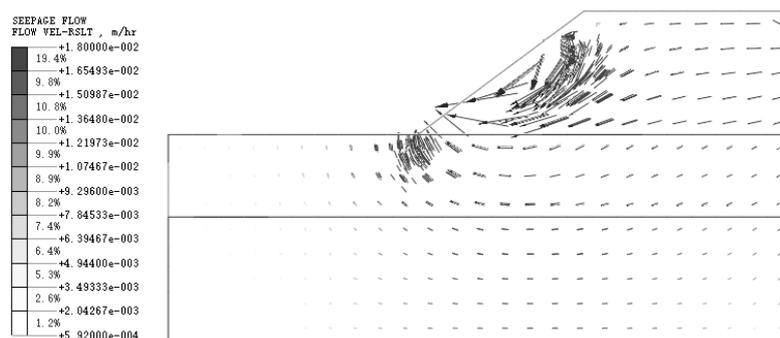
According to transient seepage analysis, the seepage path in the bank slope after the water level drops is shown in figure 13. On the figure, the seepage in the lower bank slope is still under adjustment in the first stage after the water level drops. The seepage in the upper bank slope seeps out of the slope body, but its source is not groundwater. This is because there is stable seepage in the soil above the bank slope

before the river water drops, and part of free water is stored in the pores of the soil. However, the rapid drop of the river water level makes it too late to remove some pore water in the soil. Therefore, the stored pore water will drain out of the bank slope under the action of gravity for a period of time after the water level drops. At the same time, the polymer gravel slope protection has good water permeability so that these pore water pressures can be released, thus showing the seepage path in the figure. After the water level drops for a period of time, the seepage inside the bank slope will regain its balance and form a stable seepage surface. At this time, the pore water pressure inside the slope body will regain a stable state.



**Figure 13.** Seepage path in polymer gravel bank protection slope after water level lowers.

Under the condition of keeping the water level unchanged, change the surface material in the model to concrete material, and the seepage in the bank slope under the concrete surface is analyzed using the same construction stage. The seepage velocity vector diagram in the bank slope under concrete cover in the stage of water level stabilization is shown in figure 14. On the figure, the seepage velocity under the concrete revetment surface is the fastest, which is because the seepage cannot pass through the revetment surface, and the elevation head of pore water under the revetment is difficult to drop, resulting in an increase in pore water pressure.

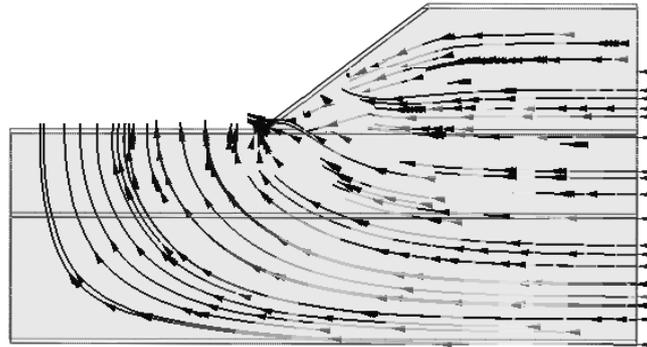


**Figure 14.** Seepage velocity in bank slope under concrete cover during stability water level.

Through transient seepage analysis, the seepage path in the bank slope after the water level drops is shown in figure 15. On the figure, compared with the seepage at the original water level, the seepage path of the concrete slope protection hardly changes after the water level drops. This is because the permeability of concrete slope protection is extremely low. The seepage mainly seeps along the slope protection surface to the toe of the slope. The rapid decline of river water level outside the slope protection will not change the seepage path inside the slope protection.

Comparing the seepage situation inside the bank slope of the slope protection with two different materials whose river water level drops rapidly, the bank slope made of polymer gravel material can

quickly remove the pore water in the bank slope and form a new stable seepage. Concrete slope protection has very little water permeability, so it is difficult to remove the pore water in the soil after the river water drops rapidly. The pore water pressure at the bottom of the slope protection acts on the slope protection, which adversely affects the stability of the slope protection structure. In addition, the internal seepage path of polymer gravel material bank slope is relatively short, and the seepage force is relatively small, which makes it difficult for the bank slope soil to undergo seepage failure.



**Figure 15.** Seepage path in bank slope under concrete cover after water level drops.

## 5. Conclusion

In this paper, the structural stability and internal force of polymer gravel slope protection and concrete slope protection are compared and analyzed by strength reduction method, steady state analysis and transient analysis are adopted. The seepage characteristics of bank slope soil under the conditions of stable river water level and sudden drop of river water level are investigated, and the conclusions are as follows:

- According to the numerical analysis of bank slope stability, compared with natural bank slope, the potential slip surface in the slope body with protective surface has moved up, and the shallow shear failure along the protective surface is more likely to occur. In addition, although the bank slope under the action of the two slope protection structures has not suffered instability damage, the stability of both slope protection structures is lower than that of the natural slope, and the safety reserve is less.
- The maximum bending normal stress of polymer gravel revetment surface decreases gradually with the increase of surface layer thickness, and the bending stress decreases more obviously when the surface layer thickness is smaller, while the maximum bending stress changes less when the surface layer thickness is larger.
- When the water level is relatively stable, the seepage of polymer gravel slope protection directly passes through the slope protection structure below the water level, while the seepage of concrete slope protection bank slope needs to go around the foot of the slope to enter the river water, which shows that the polymer gravel slope protection layer has good water permeability, while the concrete slope protection structure severely weakens the water permeability of the bank slope and blocks the supply channel of river water and groundwater on the slope surface.
- When the water level drops rapidly, the seepage in the bank slope of the polymer gravel slope protection changes downwards along with the drop of the water level. The pore water stored in the soil body will be discharged out of the slope body from the slope protection surface under the action of gravity to release the pore water pressure, thus making it difficult for the bank slope soil body to undergo seepage damage. However, the seepage velocity in the bank slope of concrete slope protection increases slightly and generates pore water pressure, which is unfavorable to the stability of the structure.

### Acknowledgments

This study was supported by the Innovation Capacity Building Project of Jiangsu Science and Technology Department (grant number BM2018028) and Hydraulic Science and Technology Project of Jiangsu Province (grant number 2018005).

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