Experimental study on anti-eroding effect of slope protected by degradable geocell

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Abstract: In order to study the anti-erosion mechanism of the new degradable geocell which is designed for slope protection and the influence of rainfall intensity and materials on its anti-erosion performance, based on the laboratory simulated rainfall tests, the erosion damage mode and water erosion of slope under the protection of linen fiber and bamboo fiber braided geocell under different rainfall intensities are studied by taking photos of the slope surface and collecting and weighing the erosion material. The results show that the new type of degradable geocell for slope protection can effectively prevent the development of slope gullies, and the slope damage is mainly splash erosion and sheet erosion. The use of linen fiber and bamboo fiber braided geocell can effectively reduce the maximum water erosion by more than 10% and the accumulated water erosion by more than 20%. With the increase of rainfall intensity, the maximum water erosion and accumulated water erosion are increased, but the increase range is 20% ~ 33% and 35% ~ 57% lower than that of bare slope, respectively. The results show that the anti-erosion ability of bamboo fiber braided geocell is slightly better than that of linen fiber braided geocell, and the ratio of maximum water erosion and accumulated water erosion reduced is slightly higher than that of linen fiber braided geocell.

1. Introduction

Water erosion is currently the most widespread and harmful soil erosion in the world [1]. Due to long-term uninterrupted rainfall, high-intensity rainfall and other complex climatic conditions, protection measures are not taken in time or the protection measures are not obvious, soil slopes are prone to severe hydraulic erosion or local slide on the shallow slope, which in turn affects the safety of the construction and operation of road slope projects.

Geocell is a new type of geosynthetic material that appeared in the 1980s. It has a three-dimensional network structure and can form huge lateral restrictions on the soil. It is often used in the reinforcement of shallow slopes. Regarding the comparison of the anti-erosion effects between different slope protection methods, Zhang [2] showed that the soil consolidation effect of the geocell under the same conditions is significantly better than that of the three-dimensional mesh mat and wire mesh. In order to slow down corrosion, the iron wire indicates that it is usually necessary to add the coating. The use and corrosion of a large area of iron wire may cause the accumulation of heavy metal...
ions in the soil, reduce the activity of root enzymes, and harm its growth [3]. And in the design of strengthening shallow slope using geocell, Wang [4] proposed the stability analysis method of flexible geocell slope protection. At the same time, Yan [5] prove that geocell has obvious anti-erosion protection effect on the residual soil slope. Based on the above researches, geocell is currently widely used in slope protection projects. At the same time, it can be used with grass-planting, three-dimensional mesh mats and other measures to achieve good slope protection effect [6].

However, most of the material of geocell used in slope protection projects currently is hardly degradable high-density polyethylene (HDPE), which has good environmental resistance and is difficult to decompose under natural conditions, leaving serious security risks for environmental protection. [7]

Aiming at the rainfall erosion of the granite residual soil slope and the environmental unfriendly problems in the current geocell slope protection, this paper developed a new type of degradable linen and bamboo geocells. Simultaneously, laboratory simulated rainfall tests were carried out under different rainfall intensities. The erosion amount and accumulative erosion amount of the slope under different slope protection forms are analyzed. On this basis, different degradable geocell materials are comprehensively compared and selected. The results of this research can provide some reference for the selection of protection measures of engineering slopes.

2. Laboratory simulated rainfall test

2.1 Test soil

The test soil is taken from the hillside opposite to the entrance material room of the Hutoushan tunnel in the TJ04 standard of Guanglian Expressway. The basic physical parameters of the test soil are shown in Table 1, and the particle size distribution curve is shown in Fig. 1.

| Class      | Water content (%) | Dry density (g.cm⁻³) | Specific gravity | Void ratio |
|------------|-------------------|----------------------|------------------|------------|
| Silty clay | 19.99             | 1.57                 | 2.54             | 0.62       |

Fig.1 Particle size distribution curve of test soil

2.2 Test device

The test device is composed of a rainfall simulator and a model test box, as shown in Fig.2. The rainfall simulator simulates rainfall with a pipe network. Flow meters and water meters are used to facilitate quantitative control of rainfall intensity.
The slope of the model is set to 30°. The sides of the test box are toughened glass which are also used for observation. The upper and lower outlets of the front of the test box are equipped with rainwater collecting plates.

The lower part of the model box is equipped with a supporting platform, which is connected by a rotating shaft to adjust the slope angle.

![Test equipment](image)

**Fig.2 Test equipment**

### 2.3 Test conditions

Since rainfall intensity is one of the main factors affecting the infiltration and runoff process of slopes, this experiment sets two rainfall conditions, low rainfall intensity (20mm/h) and high rainfall intensity (60mm/h), for comparison. In order to ensure that the total rainfall depth of the two test conditions is the same, the rainfall duration of the two are set to 6h and 2h respectively, and the total rainfall depth is 120mm.

At the same time, in order to study the anti-erosion effects of different degradable materials, tests are carried out on two types of geocells, bamboo and linen.

In this paper, a total of 6 test conditions are tested. Among them, a bare slope condition is set for comparison. Through the combination of different conditions, the influence of material of the geocell and rainfall intensity can be discussed separately. The specific test conditions are shown in Table 2.

| Serial number | Form of slope protection | Rainfall intensity (mm.h⁻¹) |
|---------------|--------------------------|----------------------------|
| 1             | Bare slope               | 60                         |
| 2             | Bare slope               | 20                         |
| 3             | Bamboo geocells          | 60                         |
| 4             | Bamboo geocells          | 20                         |
| 5             | Linen geocells           | 60                         |
| 6             | Linen geocells           | 20                         |

### 2.4 Test process

Before the tests, the angle of the model box is adjusted to the designed value and then the slope is filled in layers according to the designed dry density.

First the biodegradable geocell materials (bamboo mats, linen, etc.) were cut into 10cm wide strips
and weave them into geocells. When filling the soil to 12 cm below the upper rainwater collection plate, place the geocells in a grid-like arrangement. The geocells shall be as vertical as possible to the soil surface and fixed on the slope with U-shaped steel nails. Fill soil to 2 cm below the upper rainwater collection plate. After filling the soil, small amount of rain was applied to completely wetting the surface soil. After the slope is filled, the surface of the slope model is covered with geomembrane to prevent water evaporation and rainfall erosion when the initial rainfall intensity does not reach the design rainfall intensity.

During the test, a camera was used to record the changes in the morphological characteristics of the slope. After the rainfall begins, place a collection bucket under the outlet of the upper rainwater collection tank to receive slope runoff and erosion soil. The collection bucket will be replaced every 1 min within the first 10 min since the runoff occurs, and every 3 min thereafter. After the test, the collected material in the bucket is dried and the quality of the eroded soil is weighed.

3. Results and discussion
Erosion damage modes of slope under different protection forms, the damage modes of the slope under different protection forms are shown in Fig.3~5. It can be seen from Fig.3 that for the bare slope, the main damage modes of the slope surface are splash erosion and sheet erosion. And with the increase of rainfall intensity, the main damage mode may change to gully erosion and the erosion mass may accumulate at the foot of the slope.

The damage mode of the slope protected by linen geocells is shown in Fig. 4. It can be seen that whether under the condition of low rain intensity or high rain intensity, the slope erosion is relatively uniform, no obvious local erosion is seen, and no gully is formed.

As for the bamboo geocells, its damage mode is similar to that of the slope protected by linen geocells, that is, no obvious local erosion damage is seen, rainfall erosion is more evenly distributed along the slope surface.

![Fig. 3 Failure mode of bare slope](image)

![Fig. 4 Failure mode of slope protected by linen fiber braided geocell](image)
The test results show that under the condition of low rainfall intensity, the erosion failure modes of the bare slope and the use of linen and bamboo geocells are relatively similar, with splash erosion and sheet erosion as the main ones. With the increase of rainfall intensity, the bare slope will experience obvious gully erosion while the slopes protected by linen and bamboo geocells show lower erosion depth than the bare slope.

On the other hand, both linen and bamboo woven geocells play a role in restraining surface soil deformation, but the performance of the bamboo geocell is slightly better than that of the linen geocell.

3.1 The influence of rainfall intensity on slope erosion

Erosion amount and accumulated erosion amount are adopted here to reflect the intensity and the total effect of the water erosion. The variation of erosion amount and accumulated erosion amount with time under different rainfall intensities are shown in Fig.6~ Fig.8.

In the case of low rain intensity (R=20mm/h), the variation curve of the erosion amount of the bare slope with time is shown in Fig. 6 (a). It can be divided into two stages. The first stage is from the beginning of rainfall to about 60 minutes, and the erosion amount of the slope gradually increases from 0kg.min⁻¹.m⁻² to 0.10 kg.min⁻¹.m⁻², indicating that runoff has begun to form on the slope surface. The loose soil particles began to be entrained by the runoff and moved downwards.

The second stage starts from about 60 minutes and ends when the rainfall ends. The amount of the erosion amount is basically maintained above 0.10 kg. min⁻¹.m⁻², reaching 0.16 kg. min⁻¹.m⁻² at the highest point, which is about 60% higher than the former. At this stage, the erosion of the slope is dominated by sheet erosion. Under the condition of low rainfall intensity, the cumulative erosion of the bare slope reached 35.5 kg·m⁻² at the end of the rainfall.

In the case of high rain intensity (R=60mm/h), as shown in Fig.6 (b), the erosion damage of the bare slope can be roughly divided into three stages. Stage 1 is from the beginning of rainfall to about 10 minutes, and the erosion of the slope gradually increases from 0 kg. min⁻¹.m⁻² to 0.30 kg.min⁻¹.m⁻², which belongs to the initial stage of the erosion.

The second stage starts at about 10 minutes and ends at about 40 minutes. The amount of slope erosion is basically maintained above 0.22 kg.min⁻¹.m⁻², reaching 0.39 kg. min⁻¹.m⁻² at the highest point, which is about 78% higher than the former.

The third stage starts from 40 minutes to the end of the rainfall, at which time the erosion amount gradually increases to about 0.75 kg. min⁻¹.m⁻², and the maximum value than that under low rain intensity condition is increased by about 370%. At the same time, due to the residual soil itself has the characteristics of softening and disintegrating in contact with water, the soil on the wall of the erosion gully will slide downward many times, resulting in a short-term abnormal increase in the amount of erosion, as shown in the red dotted line in Fig.6(b).
The time-varying curve of the erosion amount of the slope protected by linen geocells under the condition of low rainfall intensity (R=20mm/h) is shown in Fig.7(a). It can be seen that the erosion damage of the slope can also be divided into two stages, the maximum erosion amount reaches 0.14 kg.min\(^{-1}\).m\(^{-2}\), the accumulated erosion amount at the end of the rainfall reaches 27.9 kg.m\(^{-2}\).

In the case of high rain intensity (R=60mm/h), the maximum erosion amount reached 0.61 kg.min\(^{-1}\).m\(^{-2}\), about 335% higher than that under the low rainfall intensity condition. The accumulated erosion amount at the end of the rainfall reaches 35.3 kg.m\(^{-2}\), which is about 26% higher than that under the low rainfall intensity condition.

The results show that, under the protection of linen geocells, with the increase of rainfall intensity, the maximum erosion amount and accumulated erosion amount both increase, but the amplitude of the increase is less than the bare slope.
Fig. 7 Water erosion of slope protected by linen fiber braided geocell under different rainfall intensities

The time-varying curve of the erosion of the slope protected by bamboo geocells under low rainfall condition (R=20mm/h) is shown in Fig. 8(a). The maximum erosion amount reaches 0.12 kg.min\(^{-1}\).m\(^{-2}\), and the accumulated erosion amount at the end of the rainfall reaches 25.5 kg.m\(^{-2}\).

The time-varying curve under high rainfall intensity (R=60mm/h) is shown in Fig. 8(b). The maximum erosion amount reached 0.50 kg.min\(^{-1}\).m\(^{-2}\), increasing about 313% than that under the lower rainfall intensity condition and the accumulated erosion amount at the end of the rainfall reached 28.7 kg.m\(^{-2}\), which increases about 13% than that under low rainfall intensity condition.

The results show that with the protection of the bamboo geocell, with the increase of rainfall intensity, the maximum erosion amount and accumulated erosion amount both increases, and the increase rate is also smaller than that of the bare slope.

To sum up, with the increase of rainfall intensity, the maximum erosion amount and accumulated erosion amount of both the bare slope and the slope protected by linen and bamboo geocells will increase. And the increase of rainfall intensity will increase the erosion intensity and the total erosion effect simultaneously.

Fig. 8 Water erosion of slope protected by bamboo fiber braided geocell under different rainfall intensities
3.2 The influence of geocell materials on slope erosion

The above analysis results show that under different rainfall intensities, the anti-erosion effects of degradable geocells are different. The results of statistics on the maximum erosion amount of geocells of different materials and the accumulated erosion amount at the end of the rainfall are shown in Fig.9-Fig.10.

Fig.9 shows that whether it is under low rainfall intensity or high rainfall intensity conditions, the maximum erosion amount is bamboo geocells<linen geocells<bare slope. Under low rain intensity condition, compared with the bare slope, the maximum erosion amount of the slope protected by bamboo geocells and linen geocells are reduced by 26.5% and 13.0%, respectively, while under high rainfall conditions, it is reduced by 34.0% and 18.2% respectively.

Fig. 9 maximum water erosion of slope with different materials

The results show that the use of bamboo geocells and linen geocells can effectively reduce the maximum erosion amount, and the reduction degree of bamboo geocells is slightly better than that of linen geocells. In addition, with the increase of rain intensity, the ratio of reduction of the maximum erosion amount of the slope protected by degradable geocells will also increase, indicating that the performance of geocells in reducing erosion intensity can be more fully utilized with the increase of rain intensity.

The reasons for the above phenomenon may be that: (1) the use of geocells can effectively change the path of runoff on slopes and reduce the energy of runoff, resulting in a decrease in the maximum erosion amount of the slope protected by geocells; (2) compared with bamboo fiber, linen fiber has higher water permeability, more prominent water absorption and softening performance, resulting in lower ability to intercept runoff than that of bamboo geocells; (3) under the condition of low rainfall intensity, the flow rate of the runoff is relatively small, and the weakening ability of surface erosion is not obvious with the use of geocells or not. With the increase of rainfall intensity, the erosion resistance of the geocells will be further developed.

Fig.10 shows that under different rainfall conditions, the accumulated erosion is the bamboo geocell<linen geocell<bare slope. Under low rainfall intensity conditions, the accumulated erosion amount of bamboo geocells and linen geocells is reduced by 28.2% and 21.3% compared with the bare slope, while under high rainfall intensity conditions, it is reduced by 45.2% and 32.6%.

The results show that the use of bamboo and linen geocells can effectively reduce the amount of erosion, and the reduction degree of bamboo geocells is also slightly better than that of linen geocells. With the increase of the rainfall intensity, the reduction ratio of the accumulated erosion amount of the slopes protected by the bamboo and linen geocells will increase. The reason may be similar to the aforementioned reasons for the difference in the maximum erosion amount of different materials.
4. Conclusion

(1) The use of new degradable linen and bamboo geocells can weaken the gully erosion damage of residual soil slopes under high rainfall conditions.

(2) Rainfall intensity affects the anti-erosion effect of linen and bamboo geocells. With the increase of rainfall intensity, the maximum erosion amount and accumulated erosion amount increase, but the increase is smaller than that of the bare slope.

(3) The use of bamboo geocells and linen geocells can effectively reduce the maximum erosion amount by more than 10% and the accumulated erosion amount by more than 20%.

(4) The erosion resistance of the bamboo geocell is slightly better than that of the linen geocell, and the ratio of the reduction to the maximum erosion amount and the accumulated erosion amount is slightly better than that of the linen geocell.

Acknowledgement:
Research on the research and development of new environmentally friendly retractable drainage body and engineering performance index test technology (201906010068).

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