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Erosion test on the fiber-reinforced soil

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ABSTRACT: Erosion tests on the fiber-reinforced sand are presented in this paper. An artificial rain and a stream of water through a pipe were applied to achieve different types of erosion actions. It was shown by the tests that fiber-reinforcing could greatly increase the sand's resistance against the erosion effect of the water stream and the rain. The fibers and the sand particles could gradually make up a filter layer during the erosion test. The filter layer could not only prevent the succeeding loss of the fine particles of the sand, but also reduce the erosion force of the water stream. It was also shown that with the same content of fibers, longer thread could get better anti-erosion effect.

1 INTRODUCTION

Fiber-reinforced soil can be considered to be a composite made of soil and continuous threads of synthetic fibers. In contrast with other geosynthetic-reinforced soil, the long slim threads may be connected with soil skeleton more effectively, so that the reinforced soil achieves higher cohesion. The outward appearance of the composite is identical to natural soil. It may have excellent environmental performance with grass growing on the surface. Fiber-reinforced soil is used mostly to construct reinforced slopes (Leflaive, E. 1988).

China has many rivers and canals. The banks of the rivers and canals are often damaged by the erosion effect of water stream. Fiber-reinforced soil has excellent mechanical, hydraulic and environmental performance (Zheng, J. Q. 1992, Zhang, X. J. 1995, Li, G. X. et al, 1995, Li, G. X. et al, 2001). It may be a cost-effective alternative to protecting the banks. In this paper, tentative erosion tests on the fiber-reinforced soil were carried out to study the anti-erosion capacity and its mechanism.

2 TEST MATERIALS

The fiber used in the test was polypropylene fiber. The average apparent Young's modulus was 700 kN/cm^2. The soil was medium sand. The particle size distribution of the sand is presented in Fig. 1. The physical properties are shown in Table 1.

Table 1 Physical properties of the sand

Name	Value
Specific gravity, Gs	2.66
Maximum dry unit weight, γ_{dmax} (kN/m^3)	18.9
Minimum dry unit weight, γ_{dmin} (kN/m^3)	14.8
Maximum void ratio, e_{max}	0.791
Minimum void ratio, e_{min}	0.402

3 TEST METHOD

To make a fiber-reinforced sample, the sand and the fiber were mixed in a barrel. The barrel was in a shape of frustum. It was 24.5 cm high. The inside diameter at the top is 27 cm, and the inside diameter of the bottom is 20 cm. The air-dried medium sand and the threads were put in the barrel in many layers to make the threads well distributed in the sand. A sample was achieved when the barrel was put upside down and moved away. The density of the air-dried sand in the barrel is 1.59 g/cm^3. The relative density (Dr) is 0.23.

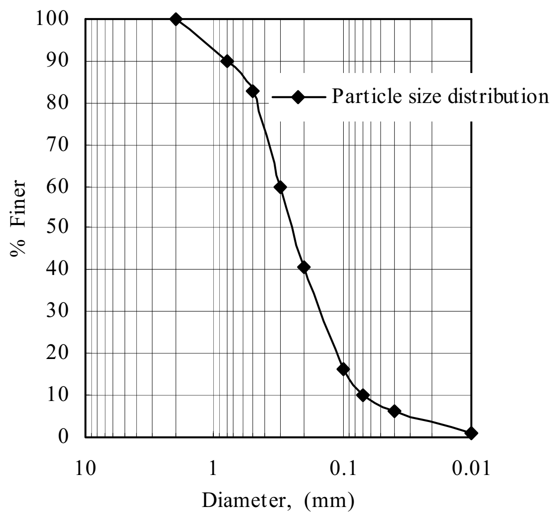

Fig. 1. Particle-size-distribution curve of the sand

For the unreinforced sand, the sample was in a shape of cone (see Fig. 2). The slope angle is about 27º. While the reinforced sand could still maintain approximately the shape of frustum (see Fig. 4), indicating that the fiber-reinforcing increased greatly the cohesion of the sand.

An artificial rain and a stream of water through a pipe (11 mm in inside diameter) were applied to achieve different types of erosion actions. The rainfall was about 4800 mm/h; The water stream could be achieved with three velocities: 1.6 m/s, 2.5 m/s and 3.1 m/s, respectively.

4 EROSION TEST ON THE UNREINFORCED SAND SAMPLE

The initial pattern of the unreinforced sand sample was shown in Fig. 2. It was found that the sand sample was demolished quickly under the 4800 mm/h artificial rain. The sand particles were carried away quickly by the water. Fig. 3 is the pattern of the sample after 2 min. in the rain. Its slope angle was about 5º. The slope would level off further if the rain continued.

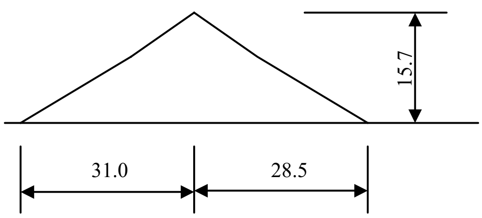

Fig. 2. Initial pattern of unreinforced sand (Unit: cm)

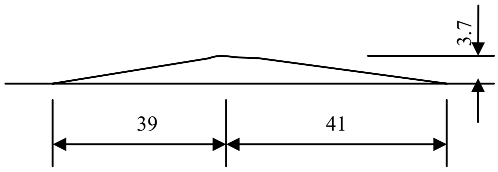

Fig. 3. Failure pattern of the unreinforced sand (Unit: cm)

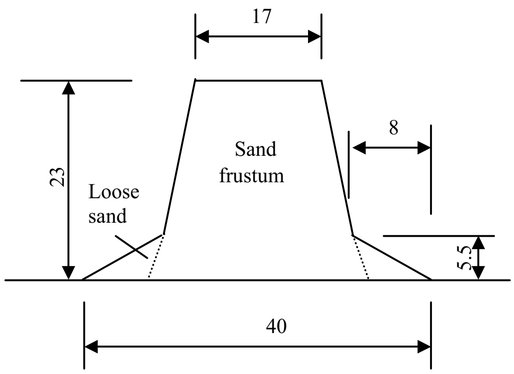

Fig. 4. Initial pattern of the fiber-reinforced sand (Unit: cm)

5 EROSION TEST ON THE FIBER-REINFORCED SAND SAMPLE

Altogether 4 samples with different fiber length and fiber content were made in the test (see Table 2).

Table 2 Fiber content and fiber length in the test

Test No.	Fiber content	Fiber length
T-1	0.2 %	30 cm
T-2	0.2 %	7 cm
T-3	0.1 %	30 cm
T-4	0.1 %	7 cm

5.1 *Test T-1, fiber content=0.2 %, fiber length=30 cm*

The initial pattern of the sample is shown in Fig. 4. The followings are the phenomena observed during the test.

① Only some sand particles on the top of the sample were washed away under the artificial rainfall. The pattern of the sample after 2 min. in the rain was shown in Fig. 5. The water carried away fine particles, while the relatively coarse particles were kept in the mesh of fibers. After the rain was kept for 4 min., it was found that not any sand could be washed away, only clear water run down the reinforced sand frustum. Comparing Fig. 5 and Fig. 3, the reinforced sand has much more resisting capacity against the erosion effect of the water.

② A stream of water with the velocity of 1.6 m/s was applied to erode the sample after the artificial rain was stopped. The stream was kept moving up and down straightaway in a line. It was found that some fine sand particles were at first washed away at the waterward side, and the stream made a groove in the frustum. However, after 2 min., no sand particle could be carried away by the stream, which meant that the balance between the erosion and the anti-erosion effect was achieved, and the erosion was controlled. The final depth of the groove was about 2 cm.

③ Kept moving the stream right and left, up and down to erode certain side of the sand frustum. After 4 min., only clear water was seen running down the slope, and no sand particles was carried away.

④ The erosion pattern was the same with ③, while the velocity of the stream was increased to 3.1 m/s. The erosion-anti-erosion balance was achieved after 3 min. The pattern of the sample is shown in Fig. 6. Clusters of threads were exposed at the waterward side. After the fine sand particles were carried away by the water, the coarse particles remained were tangled together with the threads. They formed a composite filter layer. The filter layer could reduce the erosion force of the water, and prevent the fine sand particles from further losing.

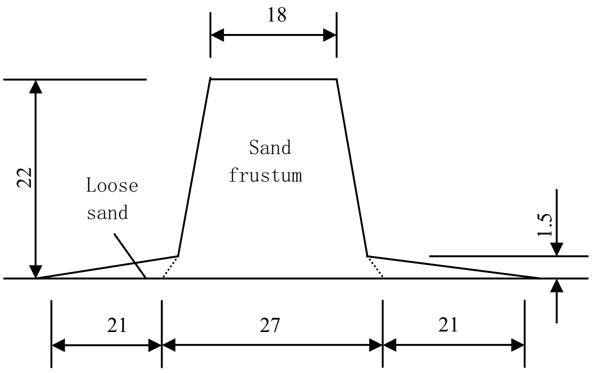

Fig. 5. Sketch of the reinforced sand frustum after 2 min. in the artificial rain (Unit: cm)

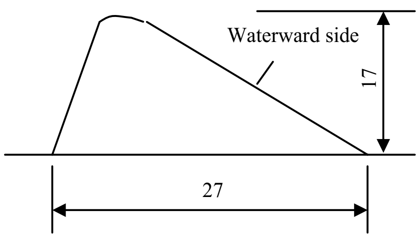

Fig. 6. Sketch of the reinforced sand frustum after 3 min. in the stream of water (Unit: cm)

5.2 *Test T-2, fiber content=0.2 %, fiber length=7 cm*

The initial pattern of the sample was approximately the same with that of T-1 (see Fig. 4). The followings are the phenomena observed during the test.

① Like T-1, only some sand particles on the top of the sample were washed away under the artificial rainfall. After the rain was kept for 4 min., not any sand could be washed away, and only clear water run down the reinforced sand frustum. The sample under the water was approximately the same with that of T-1 in Fig. 5.

②The stream of water with the velocity of 1.6 m/s was applied to erode the sample after the artificial rain was stopped. The stream was kept moving up and down straightaway in a line. After 2 min., no sand particle could be carried away by the stream, which meant that the balance between the erosion and the anti-erosion effect was achieved. The final depth of the groove made by the water in the frustum was about 8 cm. Some fibers were found being carried away by the water, because they were too short to be well anchored in the sand sample.

③ Kept moving the stream right and left, up and down to erode certain side of the sand frustum. It was found that fibers and sand particles were gradually washed away from the sample, and the frustum was gradually destroyed. After 9 min. the frustum was almost demolished like the unreinforced sand sample. Comparing to Test T-1, although the fiber content was the same with the sample of T-1, the resistance of the sample in T-2 against the erosion action had greatly declined.

5.3 *Test T-3, fiber content=0.1 %, fiber length=30 cm*

The initial pattern of the sample was approximately the same with that of T-1 (see Fig. 4). The followings are the phenomena observed during the test.

① Like T-1 and T-2, only some sand particles on the top of the sample were washed away under the artificial rainfall. After the rain was kept for 4 min., not any sand could be washed away, only clear water run down the reinforced sand frustum. The sample under the water was approximately the same with that of T-1 and T-2 in Fig.4.

② The stream of water with the velocity of 1.6 m/s was applied to erode the sample after the artificial rain was stopped. The stream was kept moving up and down straightaway in a line. The balance between the erosion and the anti-erosion effect was achieved after 2 min. The final depth of the groove made by the water in the frustum was about 4 cm.

③ Like T-1, Kept moving the stream right and left, up and down to erode certain side of the sand frustum. After 4 min., only clear water was seen running down the slope, and no sand particles was being carried away.

④ The erosion pattern was the same with ③, while the velocity of the stream was increased to 2.5 m/s. The frustum was destroyed after 4 min., which meant that the sample could not bear the erosion action.

5.4 *Test T-4, fiber content=0.1 %, fiber length=7 cm*

The initial pattern of the sample is shown in Fig. 7. The followings are the phenomena observed during the test.

① Under the artificial rainfall, some fine sand particles was first washed away, then some coarse sand particles was washed away in succession. Part of the sample was even destroyed by the rainfall. After the rain was kept for 4 min., only clear water run down the reinforced sand frustum, indicating that the balance was reached.

② Like the other tests, the stream of water with the velocity of 1.6 m/s was applied to erode the sample after the artificial rain was stopped. The stream was kept moving up and down straightaway in a line. The sample was destroyed gradually. After 1 min., it was split in two by the stream.

③ Moved the stream right and left, up and down to erode the sand frustum. The sample was demolished quickly.

6 ANALYSIS OF THE EROSION TESTS

In the tests, unreinforced sand sample were demolished quickly under the artificial rain (see Fig. 3). Sand samples reinforced with 7 cm long fibers (Test T-2 and T-4) could endure the erosion action of the artificial rain, but could not bear the action of the water stream with the velocity of 1.6 m/s. For the sand sample reinforced by 30 cm long fibers with the content of 0.1 %, it could bear the action of 1.6 m/s-velocity water stream, but was destroyed by the 2.5 m/s-velocity water stream (See Test T-3). However, sand sample reinforced by 30 cm long fibers with the content of 0.2 % could endure the erosion action of 3.1 m/s-velocity water stream. It is concluded from the tests that fiber-reinforcing can greatly increase the sand's resistance against the erosion action of the water stream and the rain. And with the same content of fibers, longer fibers have better anti-erosion effect than the short ones.

In the tests, the authors found that there were at first fine sand particles carried away by the water at the waterward side of the slope reinforced with 30 cm long fibers, while the relatively coarse sand particles remained were tangled with the fibers. They gradually made up a composite layer. The layer could reduce the erosion force of the water. The layer is also a nice filter: water could go through the layer while the fine sand particles were prohibited. However, for the sand sample reinforced with short fibers, the fibers could not be well anchored by the sand particles as well as the sand particles not well anchored by the fibers. The fiber itself might be carried away from the sand sample by the force of the water flow. So the short fibers could not effectively protect the sand sample against the erosion action.

The authors also found in the tests that when the sand samples were eroded by the water stream through the pipe, fibers at the waterward side fluctuated slightly in the water stream. But the sand particles, whether fine or relatively coarse, could not go directly through the composite layer made up of fiber and sand particles. Sand particles could only move under the layer. They were finally carried away from the reinforced frustum at the toe of the slope (see Fig. 8). When the filter layer was formed at the lower part of the sample, no sand particles could be washed away by the water.

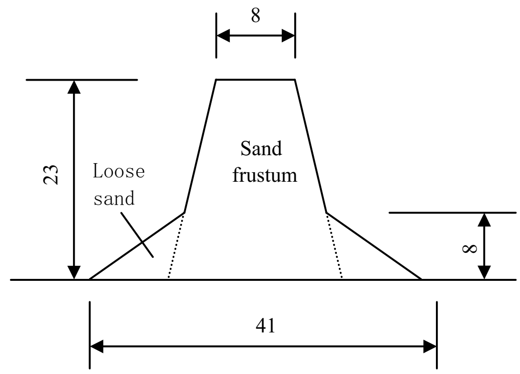

Fig. 7. Initial pattern of the fiber-reinforced sand (Test T-4, Unit: cm)

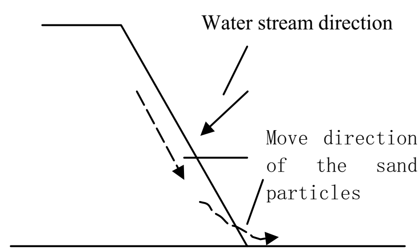

Fig. 8. Transfer pattern of the sand particles

7 CONCLUSIONS

Fiber-reinforced soil not only has excellent mechanical performance, but also has excellent hydraulic performance. It may be a promising alternative to building banks of rivers and canals. From the erosion tests on the fiber-reinforced sand samples, the following conclusions can be drawn:

(a) Fiber-reinforcing can greatly increase the sand's resistance against the erosion action of the water.

(b) In a sense, increasing the length of the fiber is more important than increasing the content. Longer threads can get better anti-erosion effect. The long fibers can well anchor the sand particles. They can make up a composite filter layer at the waterward side of the slope. Water could go through the layer while the sand particles were prohibited. However, under the erosion force of water, short fiber itself may be carried away. As a consequence, the short fiber could not effectively protect the sand against the erosion action.

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