Numerical Analysis on Protection Effects of Geotextile Mattress with Sloping Curtain (GMSC)

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Abstract: Geotextile mattress with sloping curtain (GMSC) is a new measure to solve the problems of bank erosion. A 3D numerical model of GMSC was set up by the software FLOW-3D on an unmovable bed in this paper. After simulations, the protection effects under circumstances of different velocities were studied. The results show that the length of main recirculation zone without openings is much longer than that with openings. Protected zone lengths of GMSC with openings are almost consistent, while protected zone ranges are distinctly different from each other. It is mainly caused by different velocities which can push the protected zone downstream through openings of GMSC. The distribution of velocity decreases progressively from upper right of pipe to river bed and it is consistent front and back.

Keywords: GMSC; bank erosion; 3D numerical model; recirculation zone; protected zone.

1. Introduction

With the development of harbor, coastal and offshore engineering, human beings’ life is getting closer to rivers and seas than before. Meanwhile, lots of ports, embankments and waterways are damaged, which causes millions-of-dollars loss and even threatens people’s life. All of the above is primarily due to bank collapse. Bank collapse is primarily resulted from erosion, which is the result of the interaction between current and bank. Although it is regarded as common and representative, bank erosion still has great and negative effects on people’s daily life. It may threaten dikes, channels and buildings along the shore and also may influence river bed evolution. Therefore, it is vital to protect riverbank from being eroded.

As a typical security problem in the world, numerous experts have studied protective measures against bank erosion. There have been a lot of traditional methods, such as submerged breakwaters, groins, thin walls, ecological siltation, seawalls, etc. They are made of riprap, concrete, synthetic or manufactured materials and even plants. Plants are used to protect the riverbank, like spartina alterniflora loisel and meadow grass, which are proved effective to sediment siltation and significant to improve bank stabilization. Bioengineering methods are eco-friendly and sustainable, but they are still not proper enough to be widely used because of the high cost and complex constructions. Because of the decreasing of natural rocks and the destruction of environment, it is taken into account that a new type method should be studied and proposed, which is more environment-friendly, inexpensive and convenient.

Based on the requirement of engineering, geosynthetic tubes and mattresses are proposed and manufactured [1]. Geosynthetic containers [2] can be used as construction elements for erosion control, bank-toe protection, dune reinforcement, etc. The application of geotextile containers in coastal protection works can be traced back to early works carried out in 1970s. However, water or soil filled geotextile or geosynthetic tubes [3] are not widely used for coastal or river protection projects until recent years. In the project of the shore protection [4] at
Young-Jin beach on the east coast of Korea, a double-lined geotextile tube installed with zero-water depth above crest turned out to be the most stable and effective plan after the stability analysis and hydraulic model tests. Geotextile tubes were also used as submerged dykes to solve the problem of shoreline recession not only in Malaysia [5] but also in Mexico [6]. Nevertheless, the shortages of tubes should not be ignored. The sausage shaped geosynthetic tube is found unstable and inconvenient in practice, so geosynthetic mattress is developed and applied in engineering projects, whose horizontal dimension is much greater and stability is much better than the vertical one. Then geosynthetic mattress can be fit to varieties of landscape conditions [7].

As many factors are taken into consideration, a new method against bank erosion is proposed by Xie Liquan [1], named Geotextile Mattress with Sloping Curtain (GMSC), verified by erosion experiments. GMSC has good flexibility, which will be fit to different landscape conditions. In this paper, the flow field and hydrodynamic environment around GMSC will be studied to learn the mechanism of GMSC, and the effects of GMSC with different settings to protect the bank will also be compared.

2. Structure of GMSC

The main body of GMSC is composed of geotextile mattress, sloping curtain, pipe, sand-pass openings and reinforced belt, which is improved on the base of geotextile containers (Fig. 1). The mattress is made up of two pieces of geotextiles and then divided into a string of sausage-shaped containers by sewing up. These containers can be filled with many kinds of materials, such as sand, sludge, concrete, cement, etc. In the middle of the mattress, the curtain is fixed on, which is mainly used to slow down the velocity of incoming flow. On the opposite edge of the curtain, there is a floating pipe, tubular, sealed and made with light materials, to make sure that the curtain will be stretching, explanate and freely floating. The angle of the curtain may vary with the net buoyancy provided by the floating pipe, the curtain height, the upstream velocity, openings size and location, etc. Since the sediment concentration of the flow near river bank is pretty high, openings are set at the bottom of the curtain to pass sand. After passing through the openings, sediment will settle in the recirculation area, which can increase the stability of the mattress on the erodible riverbed or seabed. Different positions and sizes of openings may lead to different effects of GMSC in sediment trapping.

Geotextile mattress with sloping curtain is much better than the one without curtain not only in total price of work, but also in environmental protection. As to mattress without curtain, although both sand and slurry can get nearby the project to fill mattress and are inexpensive, the area which needs to be covered is the whole erodible riverbed or seabed. So the quantities and costs of the project will have to increase. In the case of GMSC, small part of sediment will be intercepted and settle in front of the curtain. Most of them will deposit within a long zone behind the curtain. Therefore, there is no need to cover the whole erodible riverbed or seabed with mattress, which can save the cost, reduce the damage to aquatic ecosystem and be in response to the development trend. In addition, the mattresses with curtain can be held on their own position by deposited sediment while those without curtain may move and change their position due to the current, which means the project taking mattress without curtain may pay the extra fee. For these reasons and more, GMSC is the better countermeasure to be taken in practice.
3. Working principles of GMSC

The near-bed flow will meet GMSC and get over it. Part of the flow which is closer to the bed and with a low velocity and a high sediment concentration will go through openings on the bottom of curtain, and the most will upflow along the curtain and cross over the pipe (Fig. 2). Part of the flow crossing over the pipe will decelerate and form a top recirculation zone principally due to energy loss. The other will keep flowing and then form the main recirculation zone in the lee side of curtain. The sediment will deposit and be trapped in the main recirculation zone, and a sediment dune will take shape and gradually accumulate until the balance of sediment transportation. The sloping curtain angle varies with the flow velocity, and different angles will generate different recirculation zone in some aspects, such as form, length, distance away from curtain, etc. In this paper, the efficiency of different angles will be focused on.
4. Set-up of FLOW-3D numerical model

A 3D numerical model was set up by the software FLOW 3D to simulate experiments with GMSC and analyze the flow field around GMSC. At first, a rectangular flume was built. It was 13 m long in X direction, 0.5 m wide in Y direction, and 0.55 m high in Z direction. In the flume, the initial water depth was 0.42 m less than that in experiments (XIE) because setting of GMSC would cause water level fluctuation and it was approximately 0.2-0.4 m. The velocity was corresponding with experiments (Table 1). And the angle of curtain was decided by the velocity since the curtain could swing freely. GMSC should be installed in the middle of the flume, which could not only avoid the effects of inlet and outlet boundary, but also stabilize the flow to fully simulate the nature current. GMSC was composed of a curtain, sand-passing openings, a floating pipe and mattresses (Fig. 3). Mattresses were formed by 16 tubes with same size. Rectangle was chosen as the shape of openings after several contrast experiments of different shapes, including circle, trapezoid and rectangle. Both the diameters of floating pipes and tubes were 0.03m.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sand-pass opening size Width * Height (m)</th>
<th>Opening ratio δ (%)</th>
<th>Mean channel velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>0.0</td>
<td>0.212</td>
</tr>
<tr>
<td>2</td>
<td>0.06×0.04</td>
<td>14.3</td>
<td>0.212</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>0.171</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>0.130</td>
</tr>
</tbody>
</table>

Meshes were automatically divided by FLOW 3D, and those at GMSC (X=0) were dense by manual operation. FLOW 3D solved N-S equation by finite difference method. FAVOR™ was the unique mesh processing technic of FLOW 3D, which could describe complex boundaries more effectively and accurately. In addition, VOF, the fluid volume solving method, could trace the free-surface flow fields and offer elaborate information. All the above did help with the simulation.

5. Results and analyses
Fig. 4 showed the flow field and velocity distribution around GMSC without openings. It could be learned visually that the main recirculation zone was about 1.5 m long, where the velocity was 0 m/s or even less than that. The maximum velocity reached 0.39 m/s and it was on the upper right of the pipe downstream. In this case, the backflow during 0.5-1 m in X direction should be noticed, which reflowed from downstream to upstream close to the riverbed. It might cause the erosion around GMSC and so that the risk of GMSC being unstable would increase.

Fig. 5 showed that the maximum velocity was 0.34 m/s and there were two recirculation zones in the lee side of GMSC. Since openings were set at the bottom of GMSC, the main recirculation was separated into two parts. The smaller one was the top recirculation zone. It adjoined the upper half of GMSC and its length was about 0.3 m. The larger one was the main recirculation zone and about 0.6 m long close to riverbed. It was from X=0.3 to X=0.9, a little far away from GMSC(X=0), which was due to the openings. When flow met with GMSC at X=0, most would climb over the pipe while the other would pass through the openings and push the main recirculation zone forward.

In Fig. 6 and Fig. 7, the maximum velocity was 0.29 m/s and 0.25 m/s respectively. Both of them had two recirculation zones like group 2.

![Figure 4 Group 1](image1)

Figure 4 Group 1: $u = 0.212$ m/s, $\theta = 45^\circ$, none of sand-pass openings

![Figure 5 Group 2](image2)

Figure 5 Group 2: $u = 0.212$ m/s, $\theta = 50^\circ$, $\delta = 14.3\%$

![Figure 6 Group 3](image3)

Figure 6 Group 3: $u = 0.171$ m/s, $\theta = 60^\circ$, $\delta = 14.3\%$
After comparing these four figures (Fig. 4-7), some conclusions were available:

(1) The length of main recirculation zone without openings was much longer. The length of the main recirculation zone decided the zone protected by GMSC. However, it didn’t mean that GMSC without openings was the optimal choice to protect bank from erosion, because there was just a little sand in the lee side of GMSC without openings to deposit. If there was no opening, only a small part of sediment would get over the pipe and the rest would settle in front of curtain. When openings were set, flow with high sediment concentration would pass through them and sediment would settle in main recirculation zone behind curtain. So GMSC with openings was more effective in the aspects of protecting bank and stabilizing GMSC.

(2) Different velocities led to different curtain angles. In this paper, three groups with openings (Table 1) were picked out and studied. In Table 2, protected zone lengths of three groups were almost consistent. However, protected zone ranges were distinctly different. The protected zone started from 0.25m, which was the most close to GMSC among three groups. When the protected zone was close to GMSC, it could fill up the eroding hole on riverbed.

<table>
<thead>
<tr>
<th>Group</th>
<th>Velocity (m/s)</th>
<th>Protected zone range in X direction (m)</th>
<th>Length of protected zone (u=0m/s) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.212</td>
<td>0.25-0.9</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>0.171</td>
<td>0.55-1.25</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>0.13</td>
<td>0.45-1.1</td>
<td>0.65</td>
</tr>
</tbody>
</table>

(3) The distribution of velocity decreased progressively from upper right of pipe to river bed. Although the setting of GMSC had destroyed the continuity of flow, the velocity distribution was still consistent front and back. The maximum velocity was at the upper right of pipe and not reaching to free surface. There still was an exception. The velocity of flow passing through openings was higher than around.

6. Conclusions

Four cases of GMSC were simulated by Flow 3D on an unmovable bed, and the results were showed. Some conclusions were listed as follows:

(1) Among three cases with openings, the length of protected zone was almost consistent, and it was about 0.7 m. And there was a water drop in simulation because of the flow climbing over pipe.

(2) The distribution of velocity decreased progressively from upper right of pipe to river bed. And the velocity distribution was still consistent front and back except that around openings.
Comparing those four simulations’ results, it could be learned that GMSC with openings were more effective in sediment deposition than that without openings. The length of main recirculation zone without openings was much longer, but it wouldn’t work if there was little sediment. The setting of openings was the useful means to let most sediment pass through.

7. References