Development and application of geomat for flood defense

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ABSTRACT: The embankment failure by piping is a kind of dangerous situation usually occurred during the flood season. According to the mechanism of the embankment failure by piping, a kind of new product for salvaging failure by piping, geomat for flood defense, is developed. The geomat for flood defense consists of pressure release layer, filtration layer and protection layer. Its function is drainage and filtration, that is, to prevent loss of soil particles, to remove water seepage, to reduce full or most of seepage pressure so as to make soil structure not be changed and reach the purpose of stabilizing dangerous situation. It can salvage single piping, and also salvage a group of piping. The practices of emergency protection in flood defense during the flood season show that the geomat for salvaging failure by piping is of satisfactory efficiency, rapid salvaging speed and low labor intensity.

1 INTRODUCTION

With the previous salvaging projects of embankment failure by piping, the researchers have accumulated rich experience in the salvaging technology and devices based on the principle of "water diversion and sand restriction" and have successfully prevented various piping situations. The main methods include the inverted filter method, filter blanket method and pervious infiltration method. The main measure for salvaging embankment failure by piping is to construct a well around the piping occurrence point and to arrange filter blankets in the well. The main function of the well is to reduce the differences of water levels between the piping occurrence point and the upstream reaches of the embankment and the hydraulic gradient at the point so as to reduce the hydrodynamic pressure in the piping passage and to make the moving soil particle restore steadiness and to restrict the further development of piping. The main function of the filter blankets is to reduce the velocity of piping water at the mouth and to prevent the loss of sand particles so as to stabilize the piping situation. The wells and filter blankets may be solely or jointly employed.

The traditional filter blankets mainly employ sand material with certain gradation. The salvaging sequence is complex, and the labor intensity is large. However, the punctured non-woven geotextile has been widely applied in the emergency protection in flood defense because of its own satisfactory characteristics. It is of good filter characteristics, its strength has no obvious directivity, it is of large extension ratio and suitable for large deformation, its technology is simple, and the efficiency is good. In the previous salvaging practices, there are also some unsuccessful cases. In a word, the reasons mainly lie in (Tao & Yan,2001): (1) the shortage of knowledge of soil situation in the piping area and the characteristics of the employed geotextile; (2) the lack of relevant technicians' guidance; (3) the blindness of employing geotextile. There are various kinds of geotextile, but the salvaging situation is urgent, thus the geotextile is arbitrarily employed. It is difficult to realize the scientific match between the filter requirements and the characteristics of geotextile, leading to the failure due to siltation in the geotextile in short time; (4) the failure of geotextile. When the geotextile is employed as the materials for the filter layer, sand materials are usually employed over it as the kentledge. Thus, the filtration characteristics of geotextile, e.g., permeability, pore size and thickness, etc. may change, resulting in its failure; (5) the improper salvaging technology, etc. Therefore, the development of new products and technology for geotextile to salvage embankment failure by piping is necessary and urgent.

2 MECHANISM OF FAILURE BY AND DEVELOPMENT OF GEOMAT

During the flood season, the differences of water levels between the internal and external sides of an embankment result in the seepage motion of water. When the seepage pressure reaches certain degree, the seepage deformation will occur in the slope or ground soil at the embankment back. When the confined water of the pervious sandy ground penetrates the surface loam soil with weak permeability or the weak position of muddy soil, piping may occur. If timely salvaging is not taken, a local pervious pipe will occur at the piping point on the sandy ground, the soil particles on the embankment ground or embankment will greatly lose, resulting in cracks, settlement and failure of the embankment. The severe situation is that eddies and scouring of flows are aroused near the embankment toe at the waterside, the embankment failure is accelerated, and the embankment breaking is induced.

When piping occurs, the motion of the piping flows is similar to that of sediment-laden flows in the pipe with variable diameters. The magnitude of piping mouth, the velocity of flows, the sediment content as well as the size of sand particles are different with regard to the seepage slope, ground structure and character of pervious sandy layer. It is different from the flow regime under the condition of preventing piping from occurrence. Therefore, as for the utilization of geotextile filter layers to salvage failure by piping, besides the influencing factors for conventional filter layers, the velocity head of flows, sediment concentration by flows and particle size should be considered. They are more complex than the filter layers to prevent piping from occurrence. When the embankment failure by piping occurs, the pressure head at the piping mouth abruptly becomes the velocity one, thus, the velocity of discharge flows is large. They carry a large amount of sand particles, and the sediment-laden flows are formed. Simultaneously, because the velocity of flows inside the piping passage is not in accordance with that of the surrounding seepage flows, the velocity differences occur, and the shearing force is thus induced. It will lead to the continuous scouring of sand particles around the piping passage. Accordingly, the motion of sediment-laden flows in the pipe with variable diameters is formed. The function of the filter layers at this time is to turn the moving soil particles into static ones. The geotextile cannot be directly placed on the protected soil and is arranged at the piping mouth so as to mitigate and prevent the motion and loss of soil particles, and at the same time, the siltation of large amount of soil particles resulting in the failure of filter layers is not allowed.

Based on the characteristics of sediment-laden flows by piping, as for the filter layers for salvaging failure by piping, first, the regime of the sediment-laden flows should be controlled, and the hydraulic gradient of the protected soil should be reduced so as to mitigate its scouring action; secondly, it is not allowed that most of soil particles of the sediment-laden flows pass through the pores of the filter layers and lose; thirdly, the flows after filtration of piping should be released smoothly, and the seepage pressure should be close to 0.

3 STRUCTURE AND CHARACTERISTICS OF GEOMAT FOR FLOOD DEFENSE

The geomat for flood defense is developed considering the above three kinds of factors. It is made up of the pressure release layer, the filtration layer and the protection layer(Fig.1).

Figure 1. Picture of the geomat.

The pressure release layer and the protection layer both employ geomat. The geomat is a kind of three-dimensional and porous material manufactured by modified polyethylene that is, it is heated and melted, and then the fibers with certain diameter are extruded through nozzles and superimposed. The geomat is of certain compressive strength, thickness and porosity. The filtration layer employs specially manufactured geotextile.

3.1 *Pressure release layer*

The pressure release layer is the bottom layer of the geomat for flood defense. Its main function is to control the flow regime, to dissipate the partial velocity head of sediment-laden flows, to mitigate the pressure gradient of the protected soil as well as to reduce the scouring of flows.

During salvaging failure by piping, the pressure release layer is directly placed on the piping mouth. When the sediment-loaden flows enter into the three-directional geoomat, the vertical diffusion and plane motion of flows will be aroused. The dissipating ratio of piping head changes with the porosity

and thickness of the geomat (Yan &Tao,2001). When the thickness of the geomat is constant, the dissipating ratio of head will linearly decrease with the increase of its porosity; when the porosity of the geomat is constant, the dissipating ratio of head will exponentially increase with the increase of its thickness. The relationship among the dissipating ratio of water head(ϕ), thickness(t_m) and proportion of porosity(n_m) of geomat is (Tao & Yan,2005):

$$\varphi = 74t_m^{0.137} - 0.76n_m t_m^{0.091} \quad (1)$$

in which ϕ is the dissipating ratio of head of geomat (%) ; n_m represents the porosity of geomat (%); t_m stands for the thickness of geomat (mm).

3.2 *Filtration layer*

The filtration layer is the intermediate layer of the geomat for flood defense, and it is also the core layer. Its function is the drainage and filtration. When the sediment-laden flows reach the filtration layer through the geomat, the velocity head of flows decreases, and the distribution of velocity is uniform. At the same time, the sediment concentration by flows also decreases and exhibits uniform distribution. Accordingly, it is in favor of choosing rational filtration layers.

3.2.1 Requirements of soil conservation

The primary requirement of the filtration layer is the soil conservation, that is, the soil particles in the sediment-laden flows are not allowed to pass through the pores of the geotextile filtration layer and their loss should be avoided. Therefore, the following condition must be satisfied:

$$\frac{O_e}{d_k} \le \alpha \quad (2)$$

where O_e stands for the effective pore size of punctured non-woven geotextile (mm), taking O_e=O_{95}; d_k represents the size of particles in sediment-laden flows by piping (mm); α is the coefficient. d_k may be taken as the equivalent size d_e.

The value of α is dependent on the condition that the particles enter into the pores of the filtration layer under the action of seepage flows. If a single particle enters into the pore of the filtration layer, α =1. At this time, the failure of the protected soil belongs to the failure by piping. If many particles simultaneously enter the pore of the filtration layer under large hydraulic gradient, the particles are extruded and blocked at the pore mouth of the filtration layer, and they further block other particles to enter into the filtration layer, thus the arching effect is aroused. Accordingly $\alpha \leqslant 3$, it is suitable for the soil flow failure of the protected soil.

According to the above analysis, the soil conservation requirement of the filtration layer in salvaging embankment failure by piping is as follows:

$$\frac{O_{95}}{d_e} = 1 - 3 \quad (3)$$

3.2.2 Requirements of drainage

Another important requirement of the filtration layer is the drainage, that is, the pressure after the flows enter into the filtration layer should be close to 0. With regard to that the filtration layer of salvaging failure by piping is different the conventional filtration layers and cannot be directly placed on the soil layer of the protected soil, the previous expression for permeability requirements $k_g/k_s \geqslant$B cannot reflect its requirements of drainage.

The results of laboratory tests (Tao,1999) show the relationship between the permeability ψ and effective pore size O_{95} may be obtained. Thus, the drainage requirement of the filtration layer in salvaging embankment failure by piping is

$$\psi > 19.83O_{95}^{1.2} \quad (4)$$

in which ψ is the permittivity of the non-woven geotextile (s^{-1}); O_{95} represents the effective pore size of the punctured non-woven geotextile (mm).

3.3 *Protection layer*

The protection layer is the top layer of the geomat for flood defense. Its function is to prevent the filtration layer of the punctured non-woven geotextile from damage during its storage, transport and operation, and to ensure little change of hydraulic characteristics when the overburden layer is heavy. Therefore, it is of certain rigidity, compressive strength and porosity.

4 APPLICATION OF GEOMAT FOR FLOOD DEFENSE

During the flood season, piping occurred in the slope of Tuishanzui Drainage Station in Dongtong Lake area of Yueyang City of Hunan Province. The piping mouth is about 80 m away the downstream toe of Dongting Lake embankment, and it is 1.2 m below the water surface. The phenomenon of sand-water motion in large extent could be seen on the water surface. Based on the field sampling from the piping mouth, it is preliminarily estimated that the sand at the piping mouth is the fine sand. At once, the geo-

mat with fine sand is employed to replace the traditional sandstones and gravels to salvage the piping, and a small amount of sandstone bags are used for treatment of coverage and pressing. The specific salvaging procedures are as follows: the bank slope is cleaned, and at the bank side, four geomats are connected as an entirety by use of special plastic and placed on the piping mouth. Then 15 woven bags with sandstones are employed for treatment of coverage and pressing. After the completion of salvaging, the phenomenon of sand-water motion on the water surface is invisible. The surface of geomat for flood defense is felt by hands, and there is obvious seepage feeling and no obvious discharge of sand particles. After the observation for some time, the efficiency is good, and the piping situation is successfully salvaged (Fig. 2).

Figure 2. Picture of field salvagtion.

There are 6 salvaging participants, and the duration is 10 minutes. From the field salvaging situation, it is of advantages of rapid salvaging speed, low labor intensity and satisfactory efficiency, etc.

5 CONCLUSIONS

The embankment failure by piping is a kind of dangerous situation usually occurred during the flood season. As a new technology and device, the geomat for salvaging failure by piping is of special superiority. It is pervious and can protect the soil, and its structure is rational. The geomat is of rapid salvaging speed, low labor intensity and satisfactory efficiency, etc. It is of great value of application and popularization.

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